Consortium GARR

8° BORSISTI DAY
"ORIO CARLINI"
MERCOLEDÌ 14 DICEMBRE 2016 - ROMA

Very high throughput intra data centre communication networks based on orbital angular momentum modes in optical fibre

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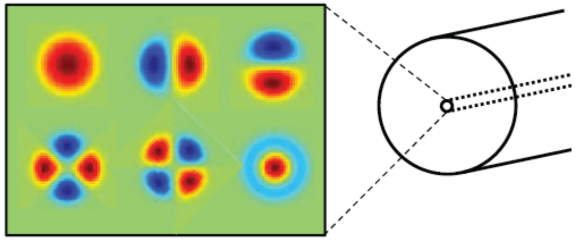
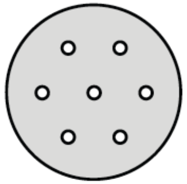
POLITECNICO MILANO 1863

Project principle

Exploit Space Division Multiplexing (SDM) to increase fibre capacity



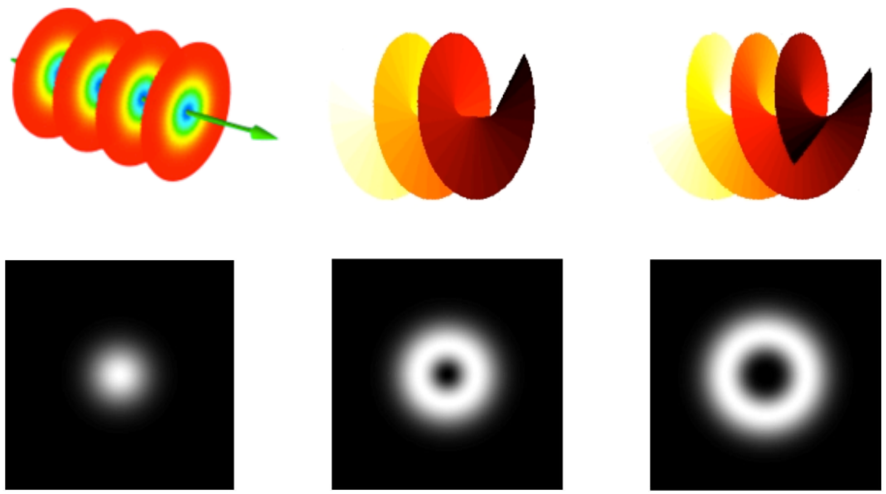
Mode division multiplexing (MDM)



Multicore fiber

Bundles of fibers

Mode division multiplexing



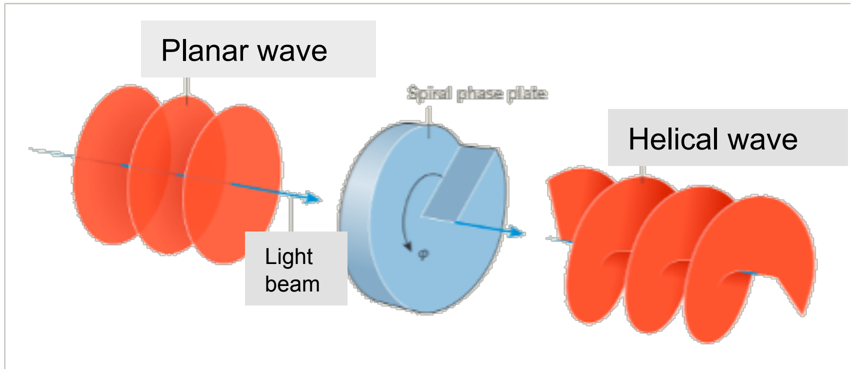
l = 0 *l* = 1 *l* = 2

Every OAM mode consists in a channel labeled by its Orbital Angular Momentum, which propagate unchanged in the fibre.

Helical wavefronts

Optical vortices

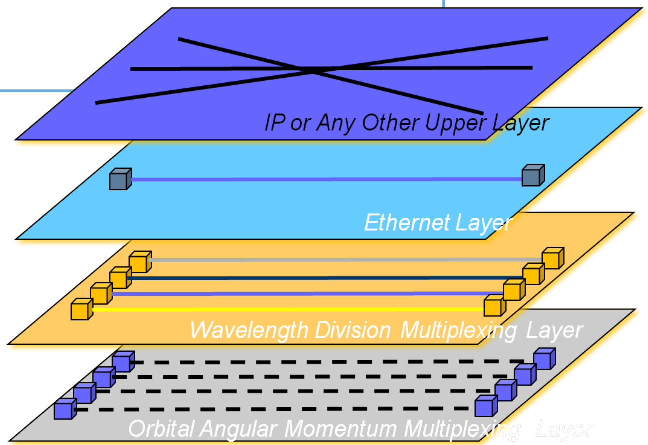
Generated from Gaussian beam by a **Spiral Phase Plate** (SPP) in free space, then injected in the fibre



Development of the OAM layer

❑OAM modes as transmission modes :
- limited intermodal crosstalk in short optical links
- enable increase of throughput

❑all-optical OAM-mode MUX/DEMUX and switching
- high speed
- energy saving



All-optical demultiplexing system

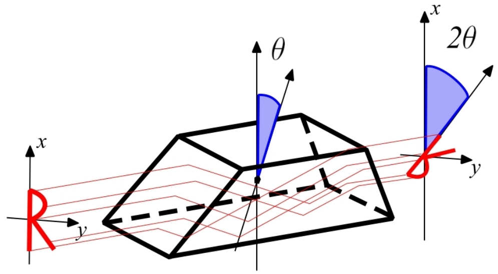
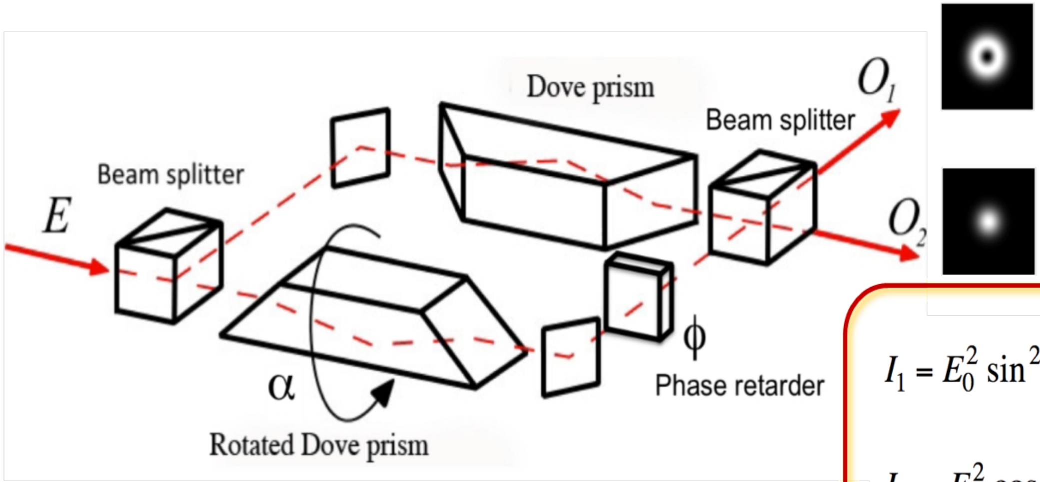


Image rotation in case of an OAM mode of order *l* is equivalent to a phase shift of **2α *l***.

Dove prisms Mach-Zender interferometer by Leach et al.



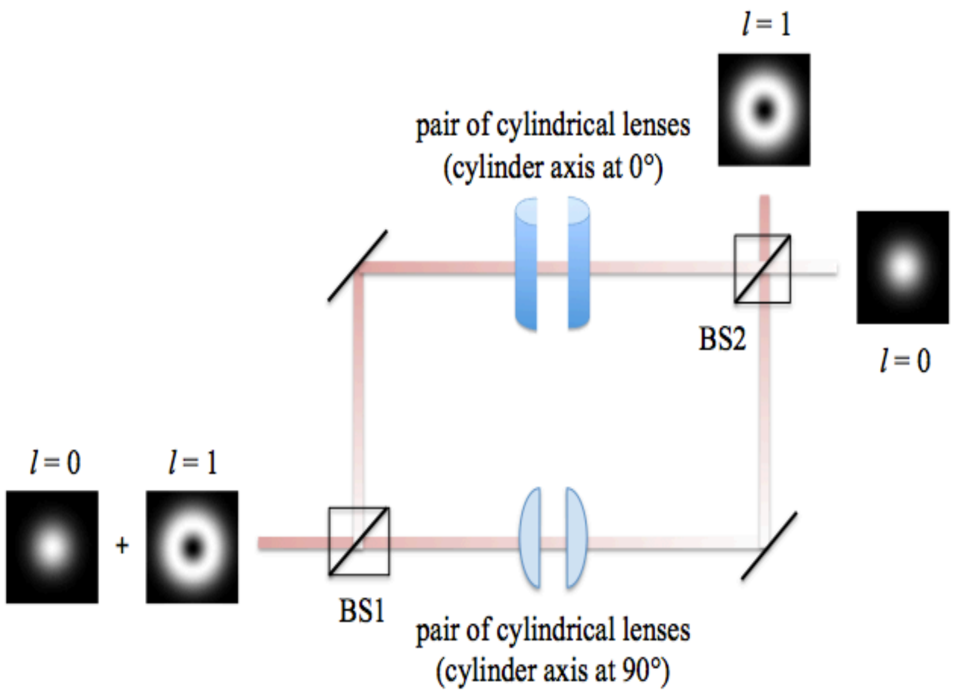
$$I_1 = E_0^2 \sin^2\left(\alpha l - \frac{\phi}{2}\right)$$

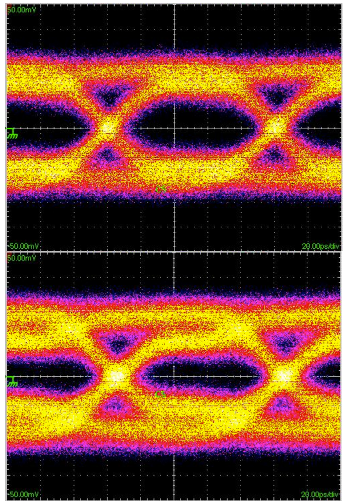
$$I_2 = E_0^2 \cos^2\left(\alpha l - \frac{\phi}{2}\right)$$

[from J. Leach et al., PRL 88, 257901 (2002)]

Our set-up for demultiplexing

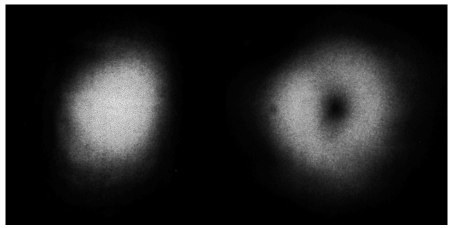
Cylindrical lenses Mach-Zender Interferometer





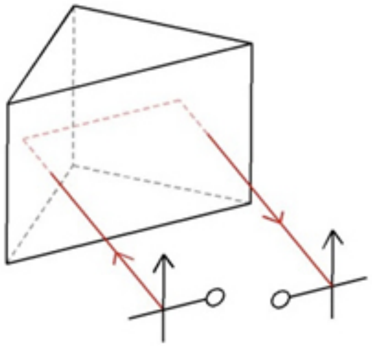
without modal crosstalk

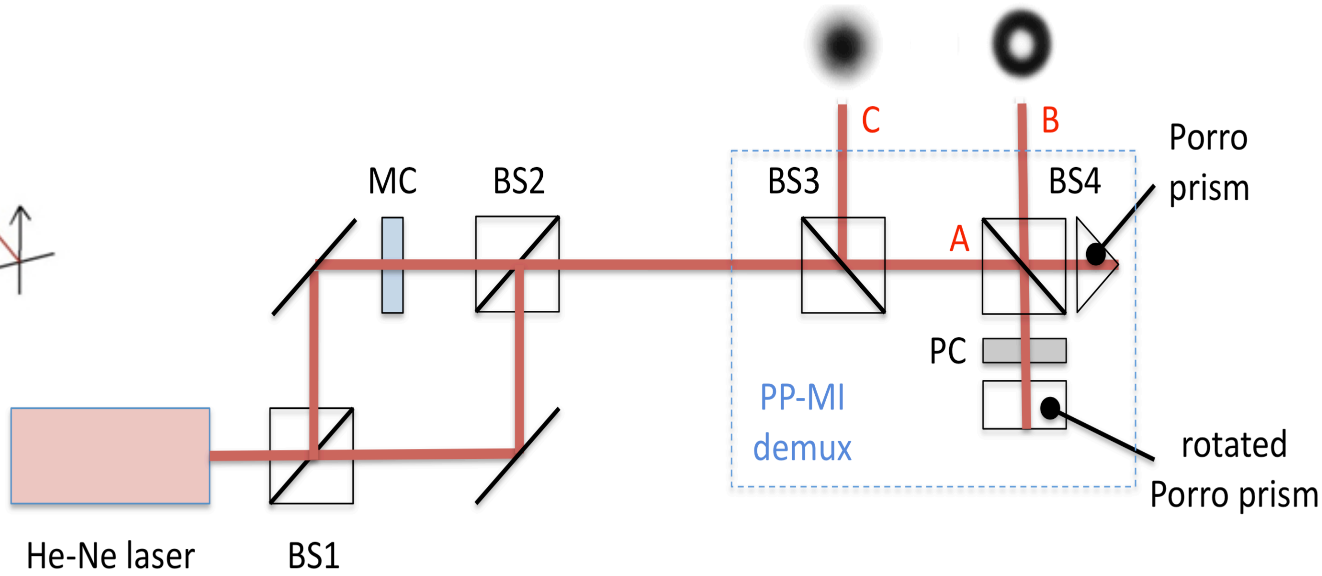
with modal crosstalk



Our set-up for demultiplexing

Porro Prisms Michelson Interferometer





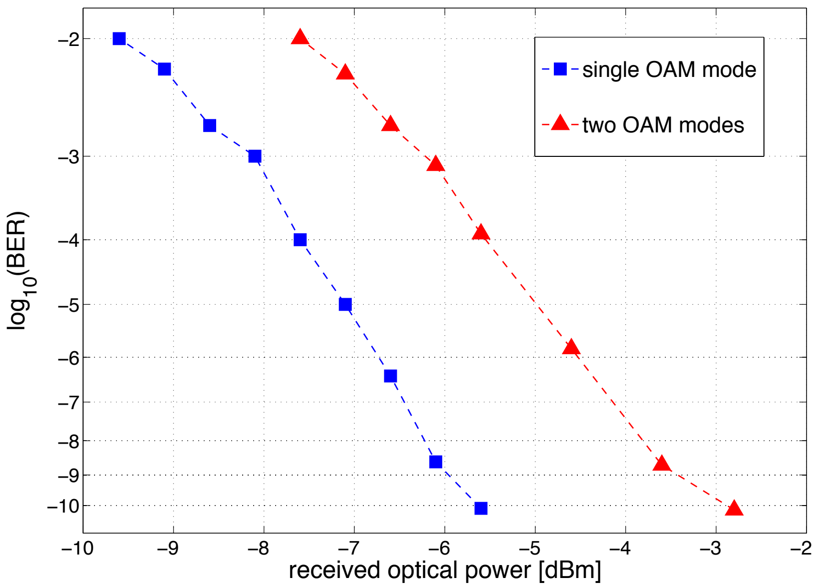
l=0 l=1

l=0 l=2

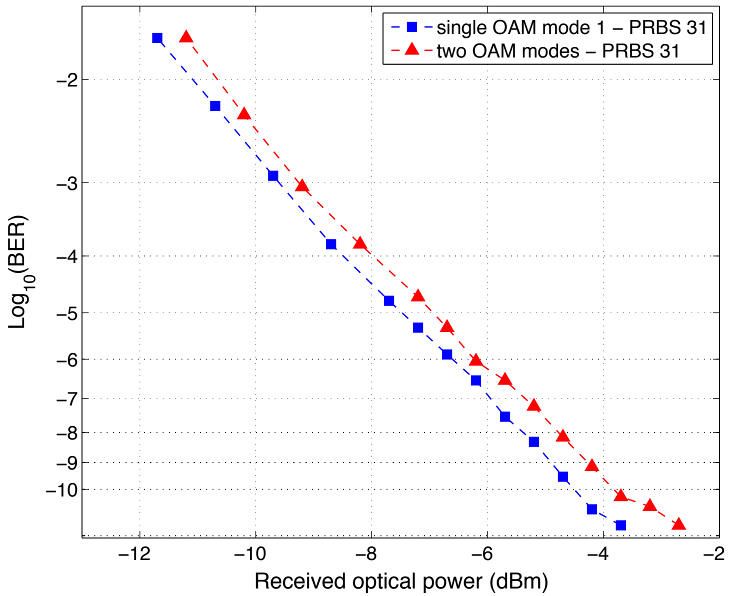
Bit-Error-Rate Measurements

Transmission of two OAM modes (of orders 0 and 1) carrying different 10-Gbit/s NRZ-OOK signals and direct detection after OAM mode demux

Cylindrical lenses

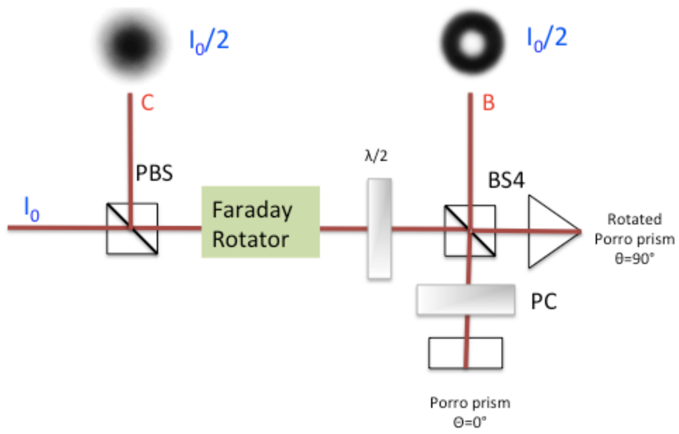


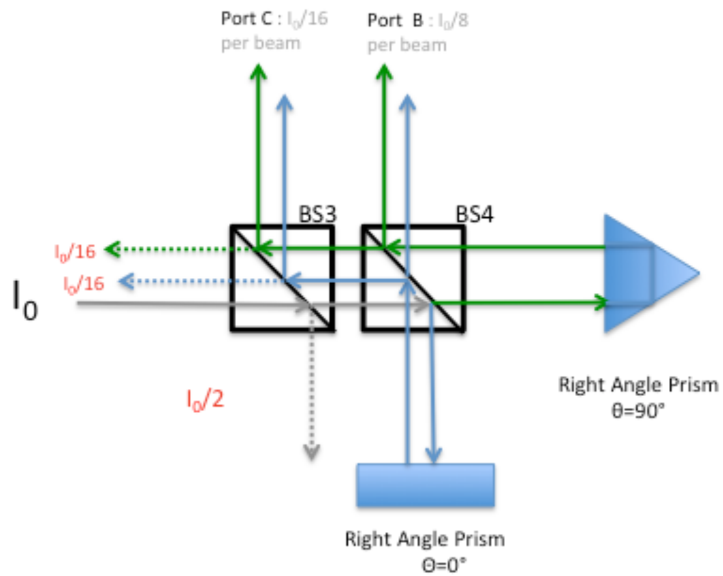
PP-MI

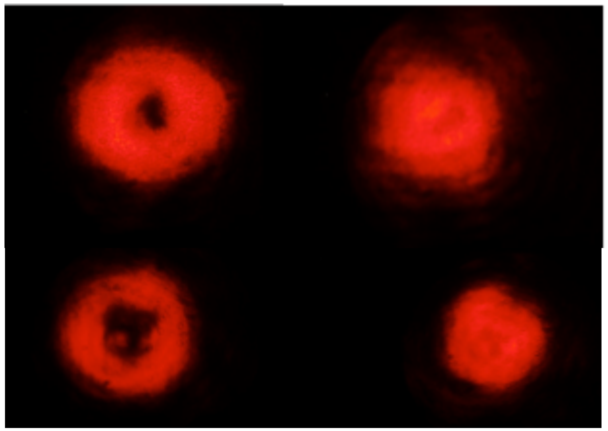


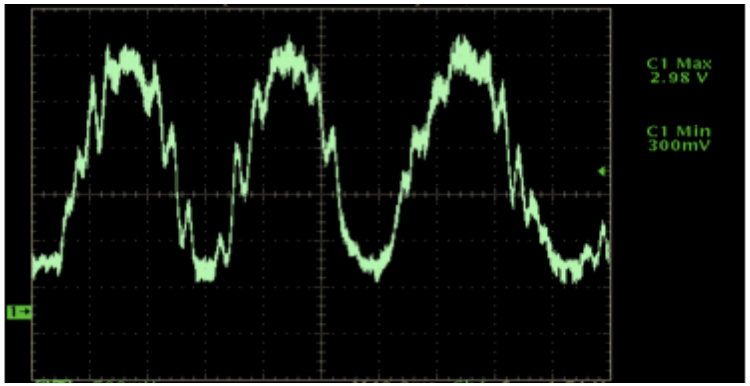
BER values measured as a function of the received optical power after OAM demultiplexing for the mode l = 0, with (red) and without (blue) the crosstalk due to the mode l = 1.

Porro-prism alternative configuration









Fringe contrast in the alternative configuration:
92% for mode 0 and 96% for mode 1

Comparisons between Porro-prisms solutions

	standard PP-MI		
	ideal	calculated by overall TF	measured
port B	0,125	0,095	0,091
port C	0,0625	0,043	0,041

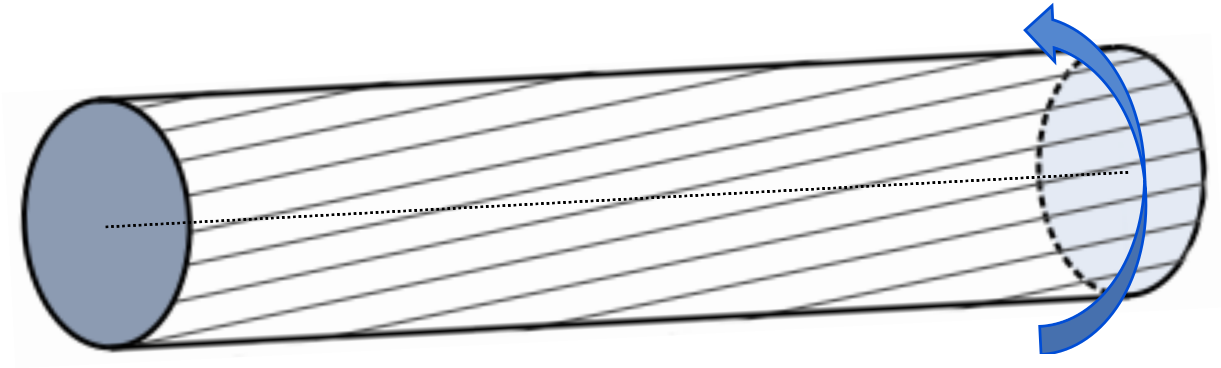
	alternative PP-MI		
	ideal	calculated by overall TF	measured
port B	0,25	0,146	0,122
port C	0,25	0,085	0,078

Table 1 Comparison of light power in the two configurations in unit of I_0

- ❑ Comparable fringe contrast.
- ❑ Reduction of power losses
- ❑ Improvement margins by replacing some components (Faraday rotator)

OAM modes transmission in stressed fibre

Fiber twist ⇔ Rotation around the longitudinal axis



Twisting rate → $\tau = \frac{\phi_{twist}}{L}$

Effect on pattern and polarization

GEOMETRIC

ELASTO-OPTICAL

Theoretical effect of twist on pattern and polarization

$$\phi_{pat} = \phi_{twist} + g/2\phi_{twist} = (1 + g/2)\phi_{twist}.$$

Geometric effect: Reference system rotation (→ ϕ_{twist})

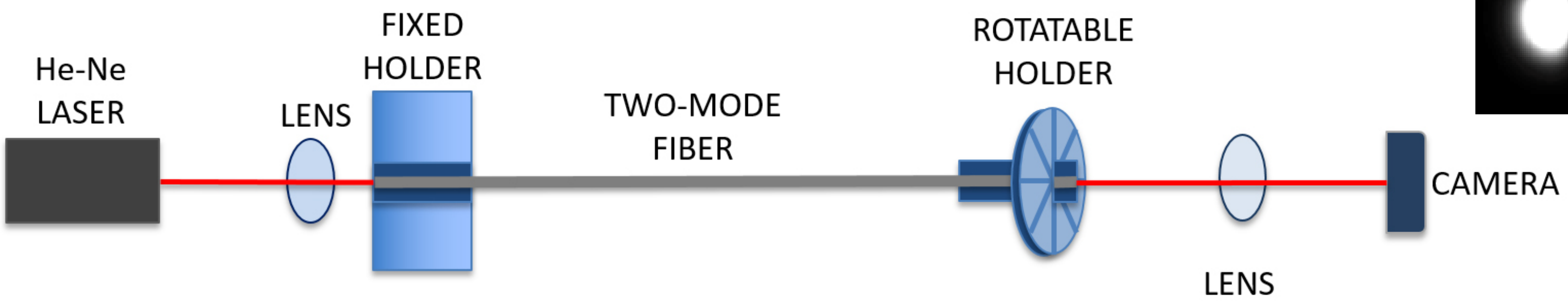
Elasto optical effect: twisting- acquired circular birifringence of the fibre (→ $g/2\phi_{twist}$)

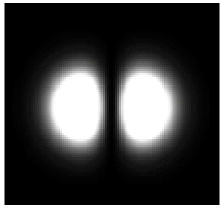
$$g = -n_0^2 p_{44}$$

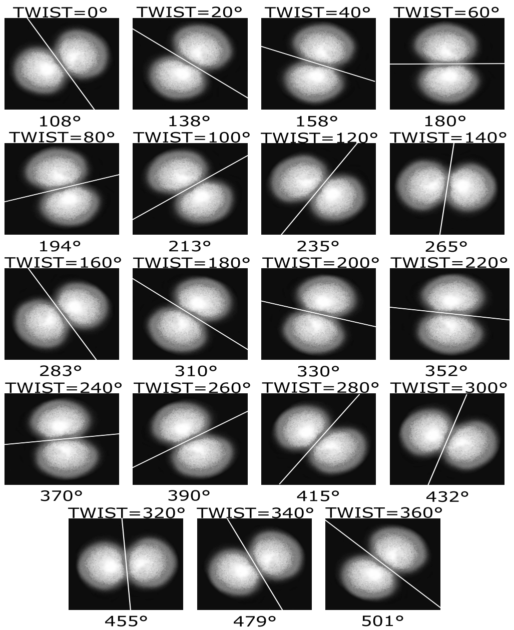
g for fused-silica = 0.16

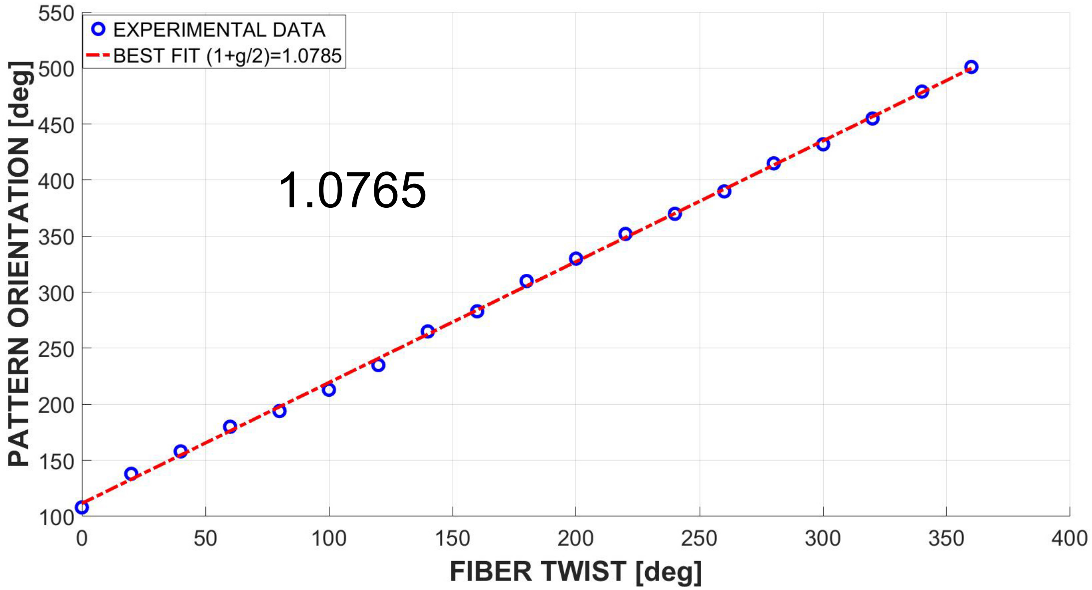
$$\Phi_{pat} = 1.08\ \Phi_{twist}$$

Experimental verification









Theoretical effect of twist on OAM modes

spin	Polarization rotation	Pattern rotation	Orbital momentum
	ϕ	ϕ	
	$e^{-i\sigma\phi}$	$e^{-il\phi}$	

PHASE TERM

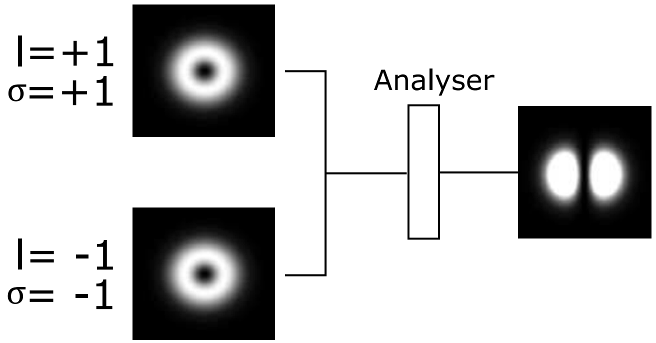
$$\gamma = e^{-i(\sigma+l)\phi} = e^{-i(\sigma+l)(\phi_g+\phi_{eo})}$$

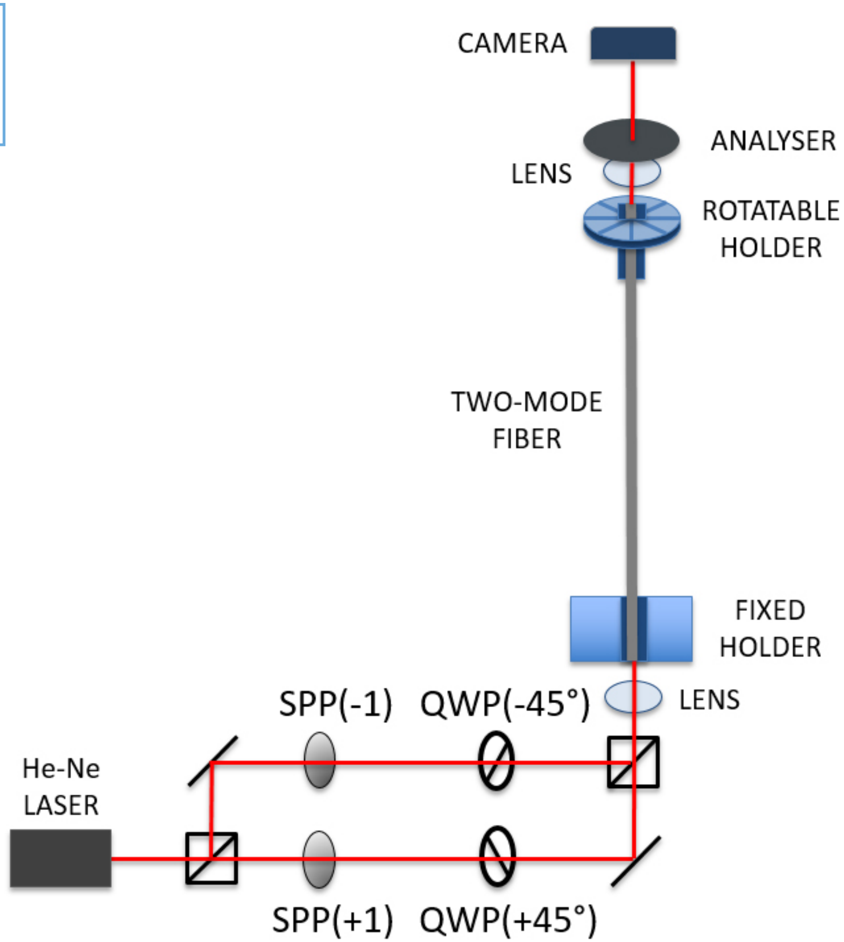
TOTAL ANGULAR MOMENTUM

$$\gamma = e^{-i(\sigma+l)\left(1+\frac{g}{2}\right)\phi_{twist}}$$

Experimental verification

In order to extract phase information we realized an interference set-up





Experimental verification

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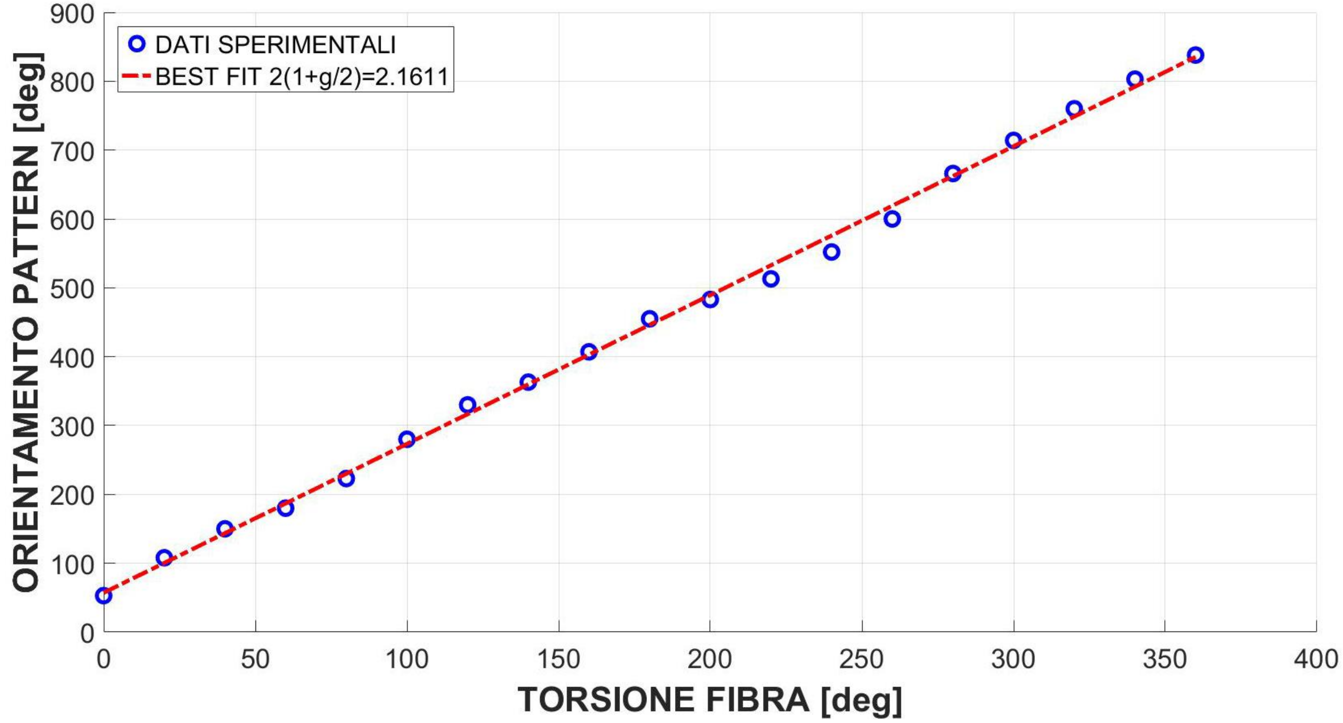
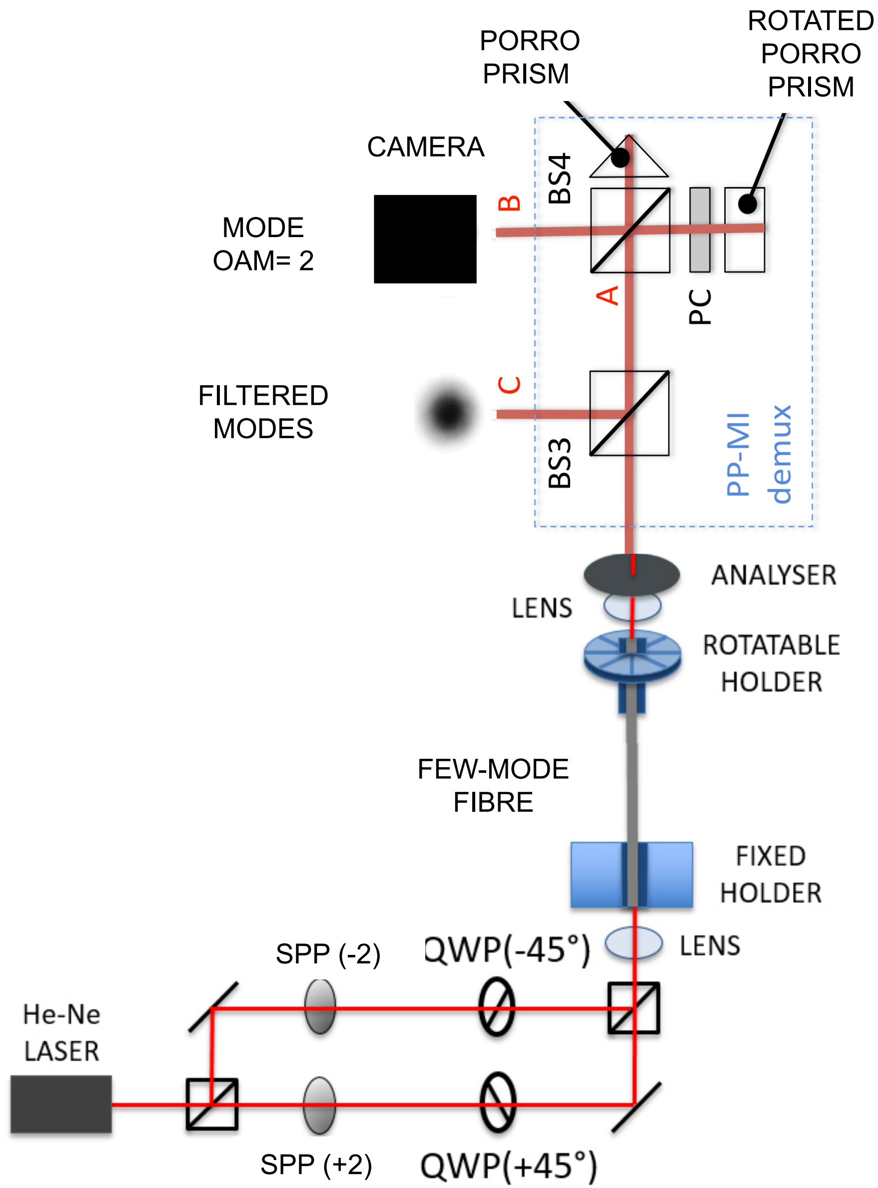
$$\Delta\theta = (1+1)(1+g/2)\Delta\phi_{twist} = 2(1+g/2)\Delta\phi_{twist}.$$



Twist-induced pattern rotation is proportional to TOTAL ANGULAR MOMENTUM

Perspectives for extension

- ❑ Verify twisting fibre image rotation for higher modes
- ❑ Studying other stressing effect on OAM modes image rotation
- ❑ Exploit fibre twisting or stressing image rotation to conceive in-fibre demultiplexer



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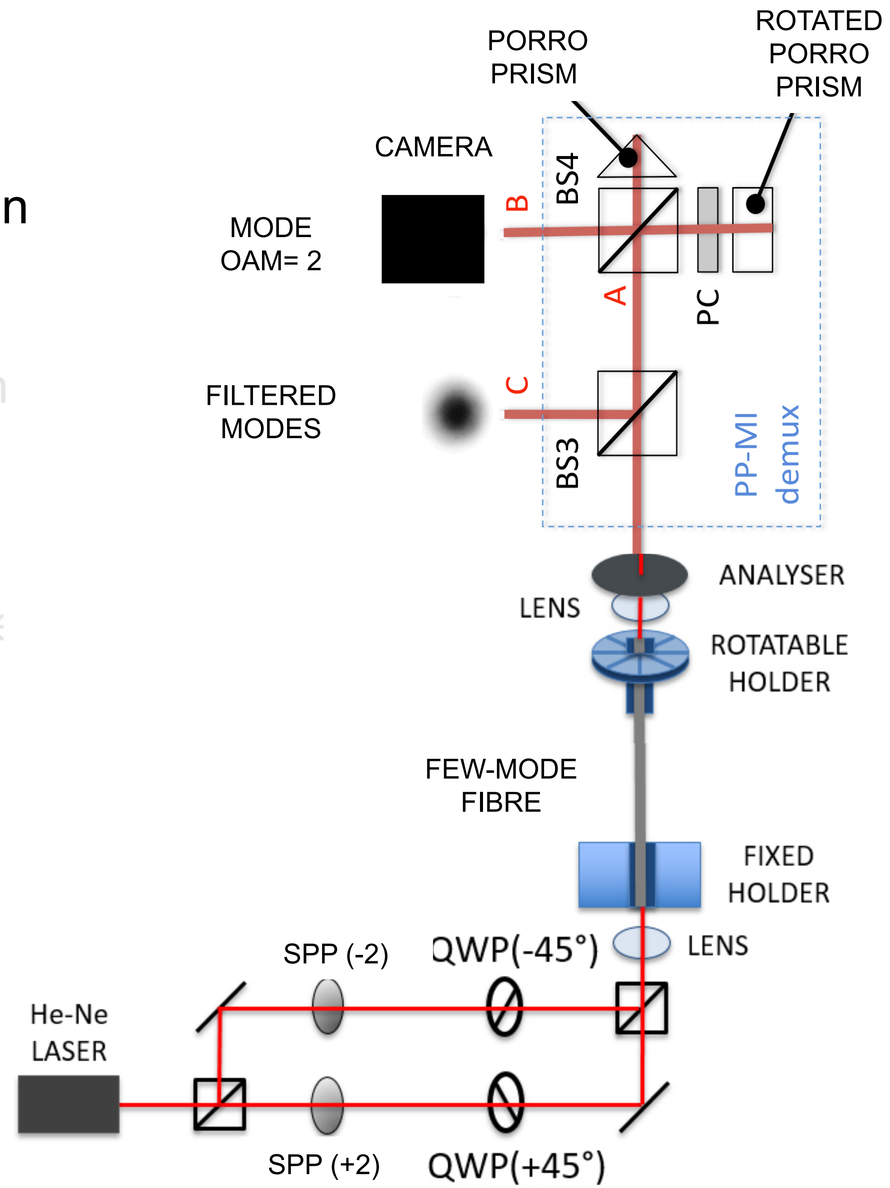
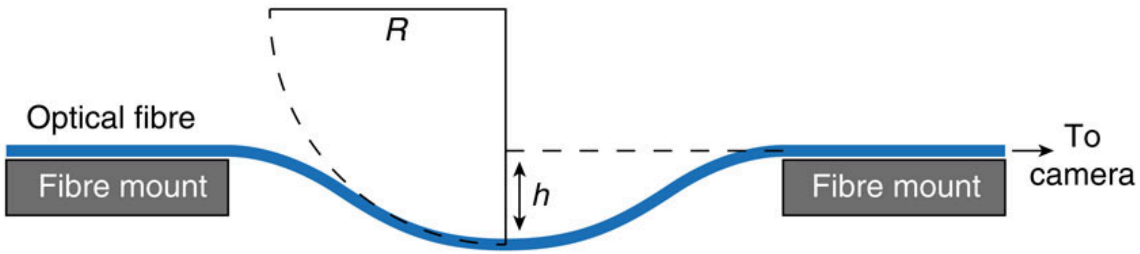
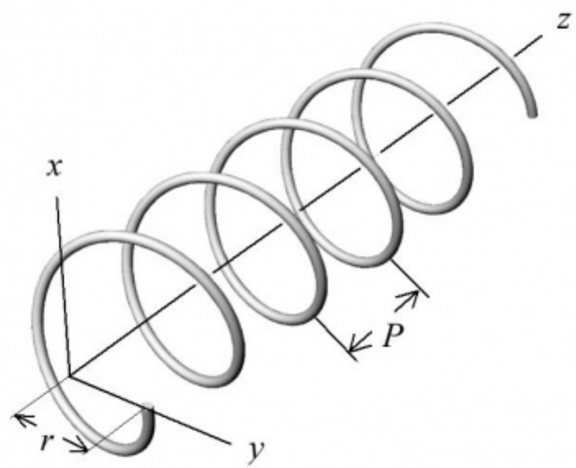


Perspectives for extension

- ❑ Verify twisting fibre image rotation for higher modes
- ❑ Studying other stressing effect on OAM modes image rotation, such as bending or helical winding
- ❑ Exploit fibre twisting or stressing image rotation to conceive in-fibre demultiplexer



Bending



Helical winding

Perspectives for extension

- ❑ Verify twisting fibre image rotation for higher modes
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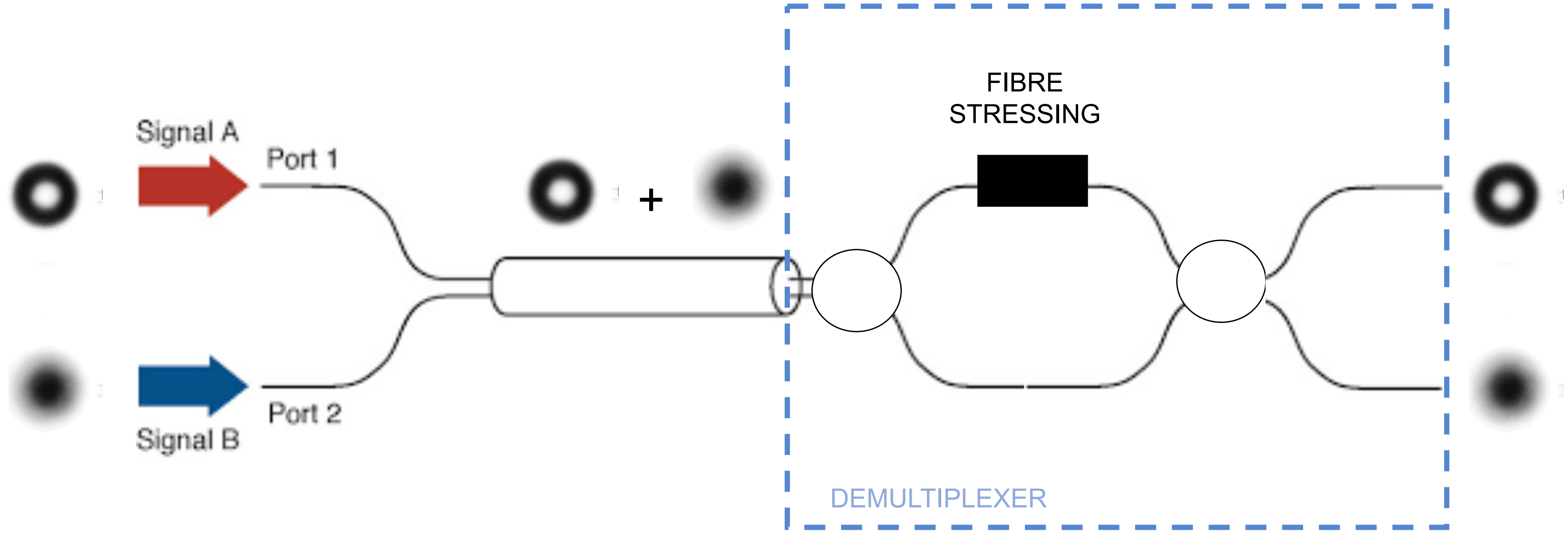
- ❑ Exploit fibre stressing image rotation to conceive in-fibre demultiplexer



Papers

P. Martelli, A. Fasiello, O. Soccali, P. Boffi, M. Martinelli,
"Angular momentum dependence of the twist-induced effect in few-mode fibres",
European Conference on Optical Communication, Duesseldorf (Germania), 18-22 settembre 2016 W.4.P1.SC1.5 (poster).

P. Martelli, P. Boffi, A. Fasiello, M. Martinelli,
"Optical mode demultiplexing for data communication networks",
International Conference on Transparent Optical Networks, Trento, 10-14 luglio 2016, Mo.B3.4 (invited).
ISBN: 978-150901467-5. DOI: 10.1109/ICTON.2016.7550268.

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