Optical detection techniques are among the most powerful methods used to characterize spintronic phenomena. The spin orientation can affect the light polarization, which, by the reciprocal mechanism, can modify the spin density. Numerous recent experiments, report local changes in the spin density induced by a circularly polarized focused laser beam. These effects are typically probed electrically, by detecting the variations of the photoresistance or photocurrent associated to the reversal of the light helicity. Here we show that in general, when the light helicity is modified, the beam profile is slightly altered, and the barycenter of the laser spot is displaced. Consequently, the temperature gradients produced by the laser heating will be modulated, producing thermo-electric signals that alternate in phase with the light polarization. These unintended signals, having no connection with the electron spin, appear under the same experimental conditions and can be easily misinterpreted. We show how this contribution can be experimentally assessed and removed from the measured data. We find that even when the beam profile is optimized, this effect is large, and completely overshadows the spin related signals in all the materials and experimental conditions that we have tested.

Spin based devices for information technology, such as magnetic memories and spin q-bits, rely on the ability to control and detect the spin orientation1–3. Optical manipulation and detection can be faster than electrical techniques while also easy to implement4–6. Unlike the electrical detection, it allows to extract pure spin-related information avoiding additional spurious effects caused by the proximity of the adjacent ferromagnet, or the interfacial spin scattering7–11. A non-vanishing spin density can cause helicity-dependent absorption of light or induce the rotation of the linear polarization12–14. This interaction, known as magnetic circular dichroism (or magneto-optical Kerr effect) has an inverse effect: the spin polarization is also perturbed by photons. It has been shown that circularly polarized15 light can induce the magnetization reversal5,16 as well as produce photovoltaic or photoresistive effects17–19. The changes of photoresistance20–21 or photocurrent22–23,26–28 have been attributed to the interaction between light and spin accumulation. This type of effect appears to be “universal”, as it has been observed in semiconductors24–27, semimetals28–30, topological insulators30–33, normal metals34–36 and even complex metal-organic structures37. However, its magnitude can differ by orders of magnitude even for similar materials and experimental conditions30–32. This significant discrepancy in the published results is indicative of at least one uncontrolled experimental parameter, related either to the material structure or to the measurement setup. Here we identify such a hidden parameter as a small beam shift that is generally produced...
when the light polarization is modified, interfering with the helicity-dependent spin signal.

The most common practical realization of experiments involving circularly polarized light, relies on the modulation of the light polarization by a birefringent crystal. The anisotropic index of refraction causes a different retardation of the orthogonal light polarizations, creating a relative phase shift that defines the resulting circular polarization. The left-hand and right-hand circularly polarized light is obtained by varying the angle between the optical axis of the birefringent crystal and the polarization plane of the linearly-polarized input light, either mechanically by rotating a quarter-wave plate ($\lambda/4$) or electrically by applying a high voltage to a photoelastic modulator. The spin-related signals are extracted from the difference of the results obtained for the two helicities of the circularly polarized light.

The variation of the light helicity is obtained by modifying the polarization dependence of the refraction index somewhere in the optical path. From the perspective of the incoming linearly polarized light, it is as if the effective refraction index is varied. Any small geometrical imperfection or slight misalignment of the optical component that is used to perform this modification will cause a change of the illumination conditions. Therefore, in the case of a focused spot, the polarization change will always be associated to a small beam shift. The question is not whether the beam shift is present, but how large it is, and how important is its contribution to the measured signal, compared to the actual spin-dependent effect produced by the circularly polarized light.

To evaluate the interplay between these phenomena, we implemented similar detection schemes as in the original studies, and focused on detecting the helicity-dependent photoresistance (HPR, this name will be used for spin-related photoresistance signal in this letter). We have tested several metallic layers and a topological insulator similar detection schemes as in the original studies. Experimental conditions. In contrast to previous reports, we have reliably separated them using a different sample geometry. Instead of a straight wire, we fabricate a ring-shaped device. Here, the effect of the HPR should be the same along the circular channel, as the spin-up and spin-down will be accumulated on the inner and outer side of the ring-shaped device (Fig. 1b). In contrast, the effect of the beam shift should exhibit a phase reversal as we move the laser along the circle (Fig. 1e) since the resulting signal is proportional to the projection of the beam shift on the sample edges. When the beam-shift is parallel to the edge, it produces no contribution to the signal. As the angle between the current and the beam shift axis is varied, the thermo-resistance reverses.

The experimental result of the 2D photoresistance mapping for the Pt ring device is shown in Fig. 1f. We observe two intersecting rings, following exactly the expectations from the beam shift-induced signal. If the experimental data included any contribution from the HPR, it should add to this effect, and the zero-crossings would no longer be at diametrically opposite positions on the ring, as shown in Fig. 1e. The relative contributions of the beam shift effect and HPR have been parametrized through an angle ($\Delta\theta$ in Fig. 1f), which quantifies the misalignment between the zero-crossings and the circle diameter. $\Delta\theta$ is $0^\circ$ for pure beam shift-induced photoresistance, and becomes $180^\circ$ for pure HPR. In our experiment, the measured $\Delta\theta$ is too small to be detected. A numerical simulation of the 2D photoresistance mapping with different HPR percentages is given in the Note 3 of the Supplementary Information. The simulation results show that $\Delta\theta$ increases with increasing the spin signal contributions to the total photoresistance. In our search for the HPR-related signal, we also measured systems such as Ta/SiO$_2$, Cu/SiO$_2$, and Pt/Yttrium Iron Garnet (YIG) (see Supplementary Information Note 5.1). The results are similar to those obtained for pure Pt, indicating that the beam shift-induced effect dominates the measured signal and no spin accumulation-induced HPR is detected.

Transverse detection of the photoresistance for improved sensitivity

In order to further improve the sensitivity of the photoresistance detection, in a second experiment we use transverse resistance measurements in a Wheatstone bridge geometry. A symmetric Hall bar can behave similarly to a balanced Wheatstone bridge: the transverse voltage is always zero, despite the application of the electric current. When an off-centered laser spot is heating the Hall cross asymmetrically, the local change in resistivity due to the laser illumination will slightly deflect the current flow, which results in a transverse voltage. This behavior is very similar to an unbalanced Wheatstone bridge, where a change in one of the resistors gives rise to a transverse voltage signal as well.

Figure 2a shows the static component of the 2D transverse resistance mapping of a platinum Hall bar, detected at the modulation frequency of the applied ac current, as the laser spot is scanned across the Hall bar. The illumination induces a localized hotspot, where the resistance increases due to heating. Consequently, the transverse resistance takes a positive or negative value depending on the position of the localized hotspot. The transverse resistance is positive if the
HPR, we observe that the photoresistance depends strongly on the keeping the optical settings unchanged. Contrary to expectations for to vary experimentally the beam shift, we rotated the sample while the direction. The calculations show that the beam shift produces a resistance change with a different symmetry than the HPR mapping.

Because of the Wheatstone bridge geometry, in the Hall bar the spin accumulation, depicted in Fig. 1a, produces a contrast with a different shape inherently will have a different effective position, which creates a different thermal gradient. To a first order, this effect can be approximated by a beam-shift. The thermal gradients produced by the oscillating beam induce opposite longitudinal resistance variations at the two edges (blue and red). This heat gradient induced photoresistance is very similar to the helicity dependent photoresistance expected in the straight device. However, for the ring shaped device in e, these two effects have different symmetries: the contrast on the edges of the device changes sign along the circle. For a straight current path and a ring device in b, the resistance mapping produced by heating with the laser spot (which can only increase the resistance) allows to foresee the symmetry of the transverse photoresistance generated by the helicity variation (which can be both positive and negative). Because of the Wheatstone bridge geometry, in the Hall bar the spin accumulation, depicted in Fig. 1a, produces a contrast with a different symmetry. In Fig. 2f, we simulate the resistance mapping expected from the pure HPR effect, which is expected to be proportional to the curl of the electric current (see Supplementary Information Note 5.2).

Similarly to the measurements on the ring-shaped device, we can now compare the HPR signals to the beam shift effect. We estimate the beam shift-induced photoresistance by subtracting the static resistance mapping from a slightly shifted version of itself. This procedure mimics exactly the experimental beam shift effect. As shown in Fig. 2g–j, the resistance mapping depends strongly on the beam shift direction. The calculations show that the beam shift produces a resistance change with a different symmetry than the HPR mapping. To vary experimentally the beam shift, we rotated the sample while keeping the optical settings unchanged. Contrary to expectations for HPR, we observe that the photoresistance depends strongly on the orientation of the sample as shown in Fig. 2b–e. These results are well reproduced by the calculated resistance mappings corresponding to a constant beam shift. Within the precision of our measurements, no other measurable signal is observed in these experiments, in agreement with the result obtained in the ring-shaped devices. Our conclusion is that the beam shift signal also dominates in the transverse configuration.

The 2D transverse resistance mapping turned out to be a sensitive method for detecting the existence of beam shift-induced resistance modification and for determining the dominant component. To confirm our conclusions, we measured 2D mappings for thin films of Au, Ta, Cu, Pt/Co/Pt, Pt/Co/AlOx on SiO2 substrate, as well as for a topological insulator layer Bi2Se3 on Al2O3 (sapphire) substrate. The results are shown in Supplementary information Note 5.3. We observe that the beam shift-induced resistance dominates in all our experiments. Moreover, since the beam shift signal has a trivial origin, we can precisely calculate its magnitude, and assess the possible presence of non-trivial components.

The transverse photoresistance is measured with high accuracy due to the Wheatstone bridge configuration. It should be noted that the method is sensitive not only to the beam shift but also to the power variation of the laser beam. This could create another component of
these effects have very different symmetries, we systematically discussed in detail in Supplementary Information Note 3.

The transverse signals that might have been neglected in the photoresistance or photocurrent experiments with the transverse configuration, e.g. in spin to charge conversion ratio estimation. Since these effects have very different symmetries, we systematically detangle them by artificially distorting the modulated laser beam, as discussed in detail in Supplementary Information Note 3.

**Beam shift magnitude estimation**

Now that we have established the prevalence of the beam shift related signal over the HPR, we can estimate the magnitude of the beam shift. From the static longitudinal resistance mapping, we calculate the beam-shift effect (for different shift values) and compare it to the experimental result (Fig. 3). We choose the direction with the largest beam shift signal. For this particular device orientation, we evaluated the beam-shift to be 19 nm. The details of the beam shift signal. For this particular device orientation, we evaluated the beam-shift to be 19 nm. The details of the beam-shift experiment (Fig. 3). We choose the direction with the largest beam shift signal. For this particular device orientation, we evaluated the beam-shift to be 19 nm. The details of the beam-shift experiment (Fig. 3). We choose the direction with the largest beam shift signal. For this particular device orientation, we evaluated the beam-shift to be 19 nm. The details of the beam-shift experiment.

The beam shift-induced photoresistance is also non-trivial when then beam diameter is large (e.g., an unfocused Gaussian beam from the laser source), for which both the width and the position of the device affect the result, as can be seen from the Supplementary Note 7. It should be pointed out that the laser beam shift is not exclusive to a single experimental setup. We used different laser diodes with wavelengths of 532, 790, 960, and 1040 nm, as well as different polarization modulators. The beam shift phenomenon always exists, varying between 5 and 25 nm depending on the setup. The beam shift photoresistance exhibits a linear relationship with the illumination power, similarly to the HPR (Supplementary Information Note 8).

To understand why this effect can be so prevalent, we made estimates of the beam shift values based on the specifications of commercial optical components. We implicitly assumed that the optical setup is perfectly aligned and the only beam shift contribution comes from the imperfections of the birefringent crystal (Supplementary Information Note 1). These estimated beam shifts are of the same order of magnitude as our experimental observations (up to tens of nm). This indicates that in most cases the effect of beam shift cannot be removed simply by adjusting the alignment of the different components. It can be reduced by using high quality optical components in combination with short working-distance objectives. However, long working-distance is often advantageous for experiments involving electric measurements to accommodate for electrical connections, while in low-temperature experiments, the long working-distance is typically imperative.

In Fig. 4 we included a graphical representation of some of the experimental parameters influencing the beam shift, as reported in several works. Different material systems such as conventional metals, topological insulators, 2D Dirac semimetals are selected. The beam diameter, device width, laser power, and wavelength, are all very different in these experiments. The beam shift-induced photoresistance is related to (a) The longitudinal resistance enhancement during illumination, which is also highly material dependent and wavelength dependent; and (b) The beam shift distance. For the beam shift distance during the measurement, the two most important factors are: (1) the effective parallelism of the helicity modulator; and (2) the working distance of the focusing objective, or in the case of un-focalized light, the distance from the helicity modulator to the device. Furthermore, for a given beam shift distance, a smaller ratio of the beam diameter/width of the device produces a larger beam shift-induced photoresistance. Among the references in Fig. 4, the effect of the beam shift-induced photoresistance is not mentioned in the manuscript, nor the working distance/parallelism of the illumination system. Consequently, this plot should not be regarded as an assessment of the quality of other works, but rather as a tool to recognize the most
significant parameters affecting the beam-shift effect in different experiments.

To conclude, we observed beam-shift-related effects in the helicity-dependent photoresistance measurement, regardless of the particular device or experimental geometry. We find that the beam shift-induced effect dominates the measured signals, and we do not find any trace of helicity-dependent photoresistance. The effect of the beam shift is not properly documented in any of the existing studies that we are aware of. The previous experiments should be revisited and possibly corrected for this effect before making any conclusions about the coupling between the circularly polarized light and spin polarization or transport, and before extracting any numerical value for any related physical parameter.

Methods
Measurement
We employed laser beams of several fixed wavelengths between 532 and 1040 nm, which were normally incident on the device. The focused spot size ranged from 1 to 4 μm, and we varied the laser power from 1 mW to 80 mW. The data in the article is with a 15 mW 532 nm laser. Three types of polarization modulators were used to modulate the helicity of circular polarization of the light at frequencies from 77 Hz to 50 kHz (f_{\text{modulation}}): 1. Photoelastic Modulator from Hinds Instruments Model PEM-100; 2. Electro-Optic Modulator from Thorlabs Model EOAM-C4; 3. Linear polarization liquid crystal retarder from Meadowlark Optics Model LVR100, in combination with a λ/4 plate from Edmund Optics (12.7 mm Dia. 532 nm λ/4 Quartz). Each polarization modulator was first calibrated. We inserted a polarizer between the detector and the modulator, and then monitored the real-time waveform of the output power. The transmitting axis of the polarizer is set to be parallel to the intermediate (linear) polarization direction, generated between the left hand and right hand circular polarized light. After fine-tuning the input signal of the modulator, the output waveform exhibited a sinusoidal waveform with a frequency of 2×f_{\text{modulation}}. Then the modulator was mechanically adjusted on a six-axis precise positioning stage. We inserted a polarizer between the detector and the modulator, and then monitored the real-time waveform of the output power. The transmitting axis of the polarizer is set to be parallel to the intermediate (linear) polarization direction, generated between the left hand and right hand circular polarized light. After fine-tuning the input signal of the modulator, the output waveform exhibited a sinusoidal waveform with a frequency of 2×f_{\text{modulation}}. Then the modulator was mechanically adjusted on a six-axis precise positioning stage. We inserted a polarizer between the detector and the modulator, and then monitored the real-time waveform of the output power. The transmitting axis of the polarizer is set to be parallel to the intermediate (linear) polarization direction, generated between the left hand and right hand circular polarized light. After fine-tuning the input signal of the modulator, the output waveform exhibited a sinusoidal waveform with a frequency of 2×f_{\text{modulation}}.
distance of 1.5 meters. The position of the modulator was further corrected by minimizing the magnitude of the FFT spectra for the transmitted laser power at the fundamental modulation frequency for a highly transparent sample. For less transparent samples, instead of the transmitted laser power, we monitored the transverse photoresistance at the fundamental modulation frequency. Details of this procedure are discussed in Supplementary Information Note 2. An AC signal at the frequency of 10 Hz \(f_{\text{current}}\) was applied to the device, with the amplitude of 5 V for the Hall bar devices and 10 V for the ring shape devices. The applied AC current and the laser modulation signal were synchronized by a NI- PXI system or two SRS 830 lock-in amplifiers, acting as a dual frequency lock-in detection. A resistor was connected in series to the device to detect the drift current amplitude and the longitudinal resistance change induced by the circularly polarized light. The photoresistance signal was measured at the frequency of \(f_{\text{light}} + f_{\text{current}}\). The longitudinal and transverse resistances measured at \(f_{\text{current}}\) reflect the static electric properties, referred to as static resistance in this article. A fast silicon optical detector was placed behind the sample (without any optical components in between) to monitor the real-time power variation of the transmitted laser beam. The sample was set on an x-y axis stepper motor stage for scanning. All the measurements were performed at room temperature.

Sample fabrication
The metals were deposited, either by DC sputtering or E-beam evaporation, on a transparent glass substrate. The deposition was followed by a two-step photolithography process to fabricate the devices and remove the photoresist at the end of the process. The thickness of Pt is 3 nm for ring-shaped devices and 6 nm for Hall bar devices. Both sputtering and E-beam evaporation were used for Pt film deposition, and no clear difference in photoresistance is found for the different deposition methods. Au (5 nm, evaporation), Pd (5 nm, evaporation), Ta (5 nm, sputtering), Cu (5 nm, sputtering), Pt/Co/Pt (3 nm/0.6 nm/1.8 nm, sputtering), Pt/Co/AIO\(_x\) (3 nm/3 nm/2 nm, sputtering) were deposited on SiO\(_2\) substrate. 10 nm thick Bi\(_2\)Se\(_3\) is grown on sapphire deposition methods. Au (5 nm, evaporation), Pd (5 nm, evaporation), Ta (5 nm, sputtering), Cu (5 nm, sputtering), Pt/Co/Pt (3 nm/0.6 nm/1.8 nm, sputtering), Pt/Co/AIO\(_x\) (3 nm/3 nm/2 nm, sputtering) were deposited on SiO\(_2\) substrate. 10 nm thick Bi\(_2\)Se\(_3\) is grown on sapphire substrate by molecular beam epitaxy in the van der Waals regime. The details of the fabrication can be found in our previous publications. The size for the Hall cross device is 50 \(\mu\)m \(\times\) 30 \(\mu\)m for metallic films, and 10 \(\mu\)m \(\times\) 10 \(\mu\)m for the topological insulator. The ring-shaped device has a width of 30 \(\mu\)m and a diameter of 200 \(\mu\)m.

Data availability
The authors declare that all the data used to reach the conclusions, and necessary to reproduce the results, is presented in the manuscript and the supplementary information.

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Author contributions
H.Y. and I.M.M. conceived the study. H.Y., E.S., and I.M.M. performed the photoresistance measurements with the help of P.J., J.N., and I.J. H.Y. fabricated the metallic samples with the help of G.G. and S.A. T.G. and M.J. fabricated the topological insulator samples. H.Y. and I.M.M. wrote the manuscript with input from all authors. All authors contributed to the discussion of the results and their interpretation.

Competing interests
The authors declare no competing interests.

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