Towards Single-Shot Spatio-Temporal Characterisation of a Multi-PW Laser

C.Eberle[1], A.Döpp[1] and S.Karsch[1,2]

1) Ludwig-Maximilians-Universität München, Am Coulombwall 1b, 85748 Garching
2) Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Why bother?

Many applications, e.g. laser driven particle acceleration require the highest of peak intensities. Spatio-temporal couplings (STCs) cause spatial and/or temporal broadening of a laser pulse in the focus, and therefore directly influence the attainable peak power.

Conversely, the controlled use of STCs enables new techniques for laser-plasma accelerators such as twisted wakefield accelerators[1] or spatio-temporal control of laser intensity by chromatic focusing.[2]

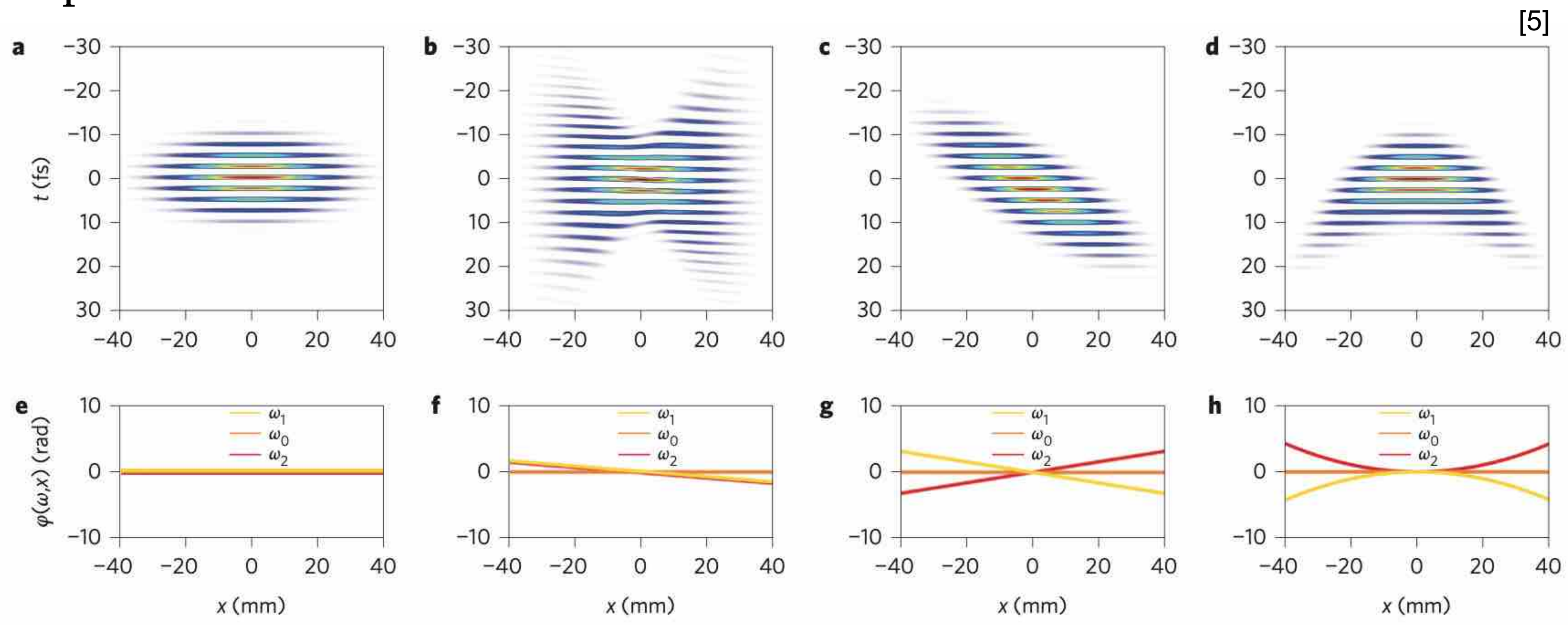
Spatio-temporal couplings

Spatio-temporal couplings are couplings between a laser's transverse profile and the time domain.

- Caused by the most common of optical element, e.g. lenses and mirrors
- Mathematical description of first order couplings via correlation coefficients known from statistics[3]

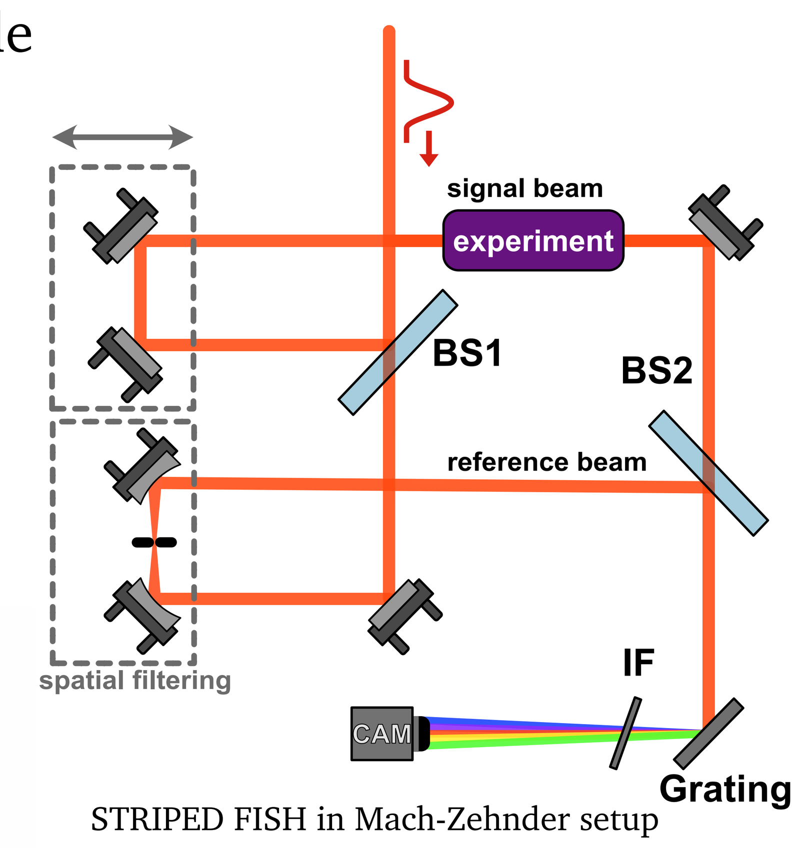
$$\rho_{xt} = \frac{\iint xt\, I(x,t)\, dx\, dt}{\sqrt{\iint t^2 I(x,t)\, dx\, dt}\sqrt{\iint x^2 I(x,t)\, dx\, dt}} = \mathrm{Corr}(x,t)$$

- Not limited to the (x,t) domain, (k,t), (x,ω), (k,ω) domains also possible via Fourier transform

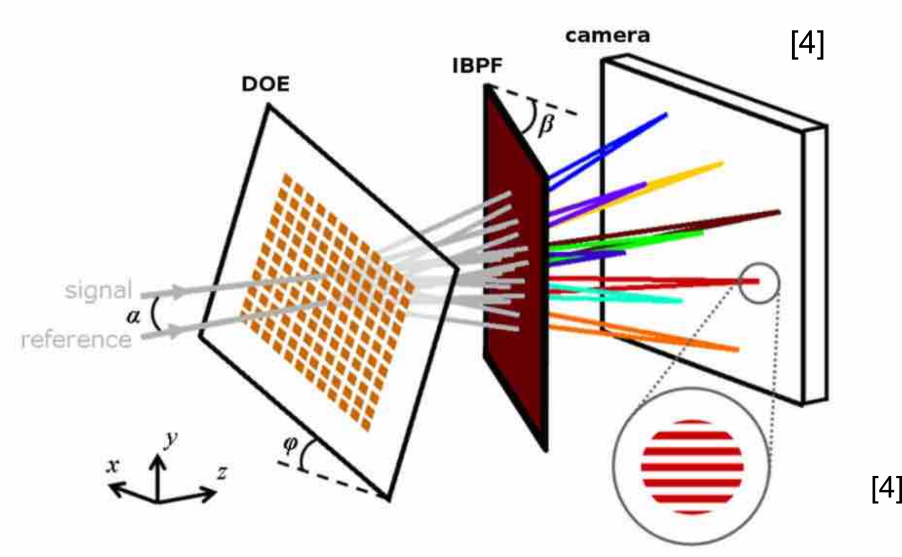


STRIPED FISH[4]

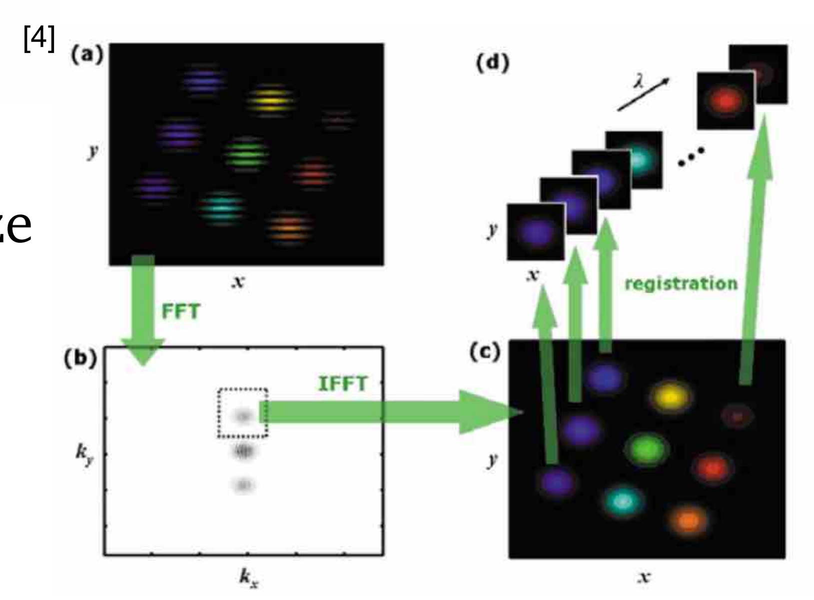
- Single-shot phase and amplitude reconstruction based on wavelength multiplexed holography
- Recover spectral electric field $E(x,y,\omega)$ from interference fringes of near-monochromatic holograms using 2D Fourier filtering.



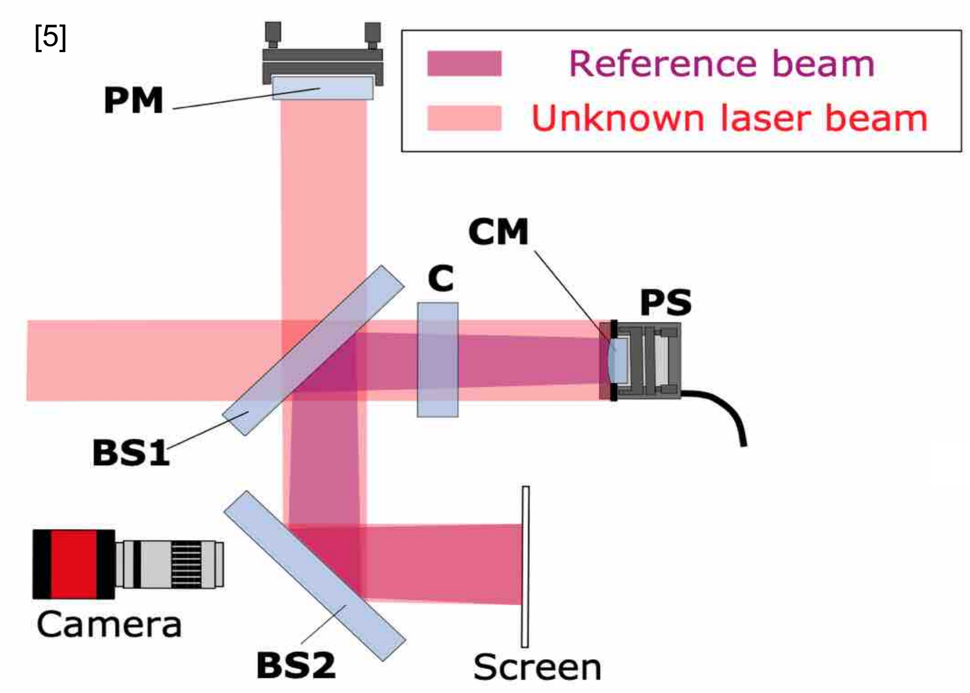
STRIPED FISH in Mach-Zehnder setup



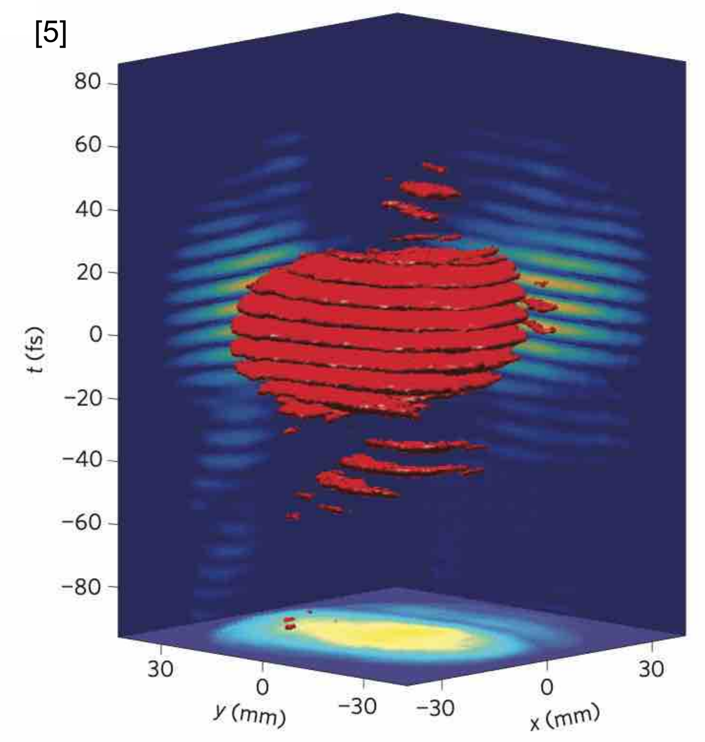
- Trade-off between spatial and spectral resolution on fixed-size sensor
  - → Larger holograms favour spatial resolution
  - → More holograms favour spectral resolution



TERMITES[5]



- Interferometric cross correlator in Michelson setup with spherical wave as reference beam
- Interference fringes contain phase and amplitude information of the signal pulse

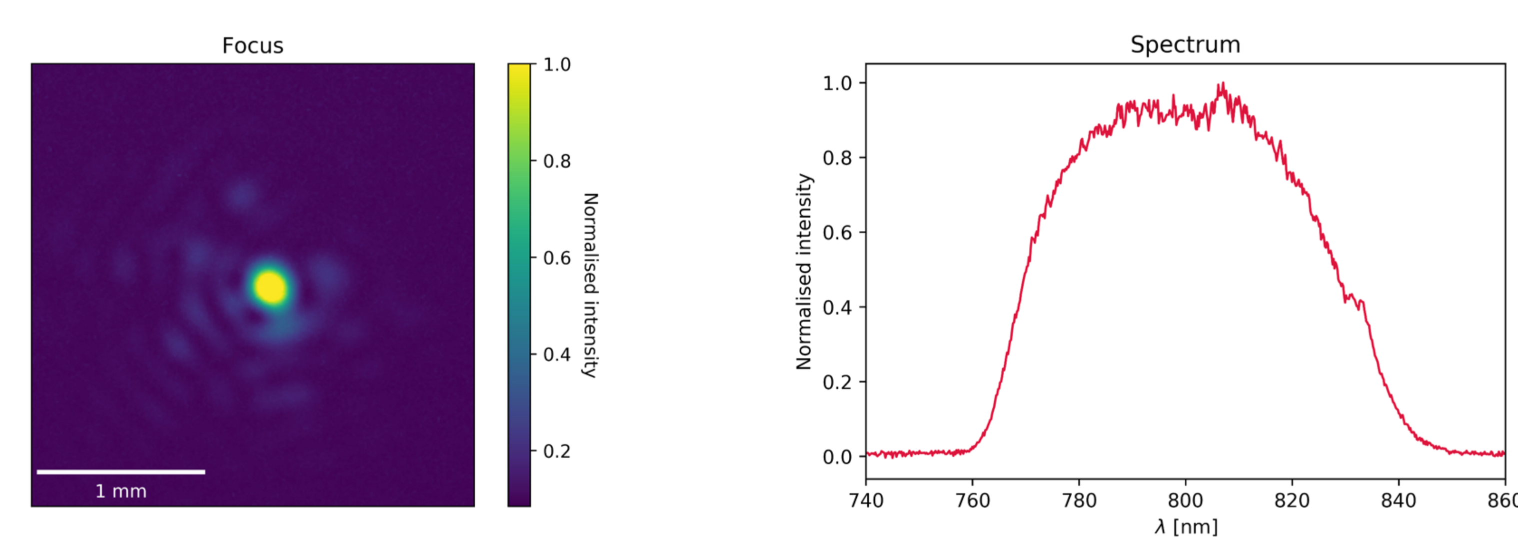


- Scan over temporal pulse envelope yields 3D cross correlation function $\mathcal{C}(x,y,\tau)$
- Iterative phase reconstruction using Fourier filtering
- High resolution but requires $\sim$1000 shots per reconstruction

ATLAS-3000 at CALA

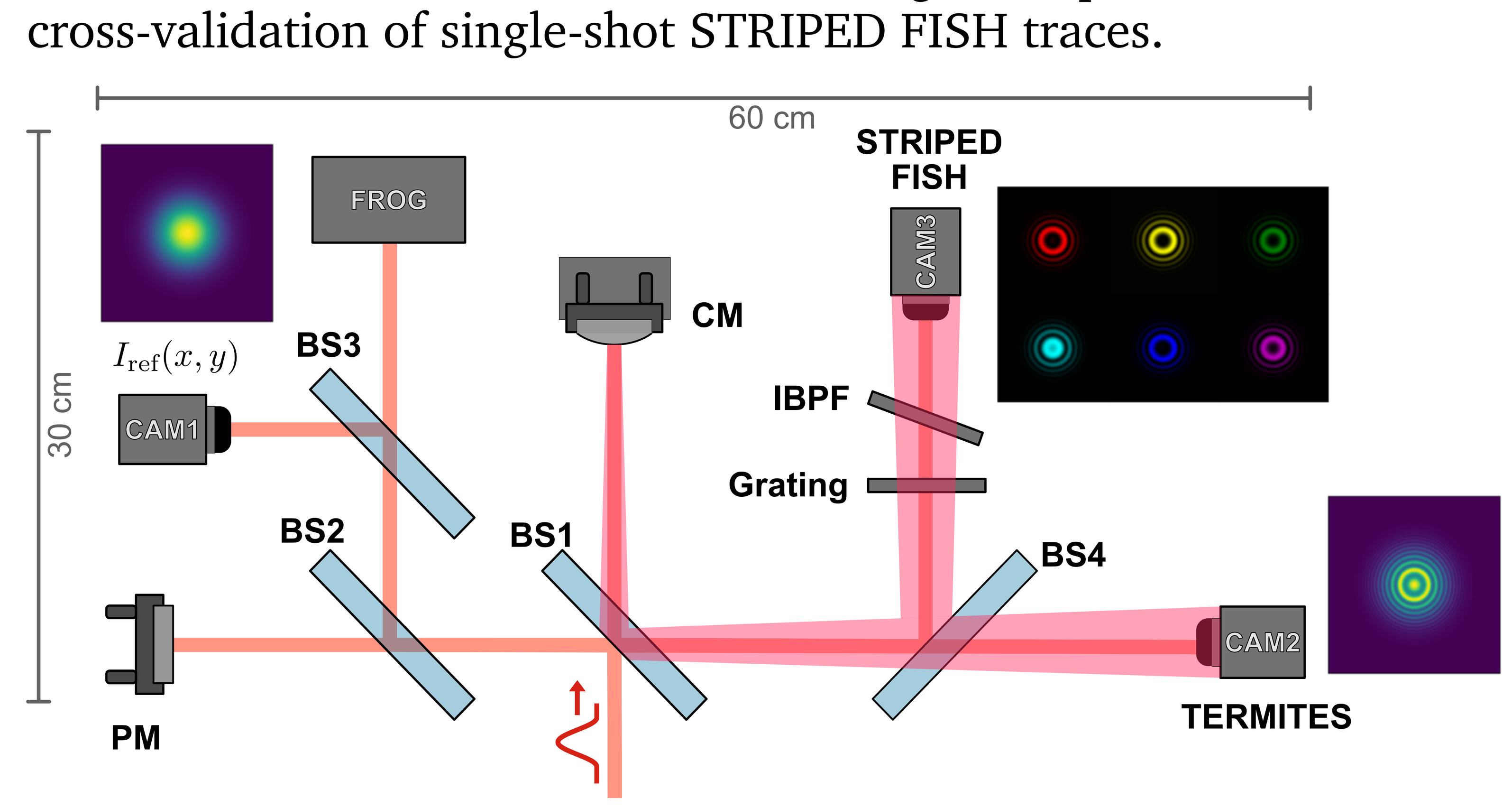
ATLAS-3000 functions as the main driver for high-intensity applications such as laser-wakefield acceleration at CALA.

The pulses from the former ATLAS-300 frontend are amplified to 90 J, resulting in parameters up to $P_{\mathrm{peak}} = 3\mathrm{PW}$, $t_{\mathrm{FWHM}} = 20\,\mathrm{fs}$ and $E_{\mathrm{pulse}} = 60\mathrm{J}$.



Experimental setup

The goal is to characterise the ATLAS-3000 laser using a robust, single-shot and portable setup. For this we propose a combination of TERMITES and STRIPED FISH into a single setup, that allows for cross-validation of single-shot STRIPED FISH traces.



- Can be operated in single-shot *and* multi-shot (scanning) mode
- High resolution TERMITES trace and low resolution but stable against shot-to-shot fluctuations STRIPED FISH trace
- Equal dispersion in every arm means equal dispersion in both traces.
- Intensity reference measurement and FROG trace in parallel to STRIPED FISH and TERMITES measurement → high efficiency

References

[1] Vieira, J., Mendonça, J. T., & Quéré, F. (2018). Optical control of the topology of laser-plasma accelerators. Physical Review Letters, 121(5), 054801. https://doi.org/10.1103/PhysRevLett.121.054801

[2] Froula, D. H., Turnbull, D., Davies, A. S., Kessler, T. J., Haberberger, D., Palastro, J. P., … Shaw, J. L. (2018). Spatiotemporal control of laser intensity. Nature Photonics, 12(5), 262–265. https://doi.org/10.1038/s41566-018-0121-8

[3] Gabolde, P., Lee, D., Akturk, S., & Trebino, R. (2007). Describing first-order spatio-temporal distortions in ultrashort pulses using normalized parameters. Optics Express, 15(1), 242.

[4] Gabolde, P., & Trebino, R. (2006). Single-shot measurement of the full spatio- temporal field of ultrashort pulses with multi- spectral digital holography. 8.

[5] Pariente, G., Gallet, V., Borot, A., Gobert, O., & Quéré, F. (2016). Space–time characterization of ultra-intense femtosecond laser beams. Nature Photonics, 10(8), 547–553.