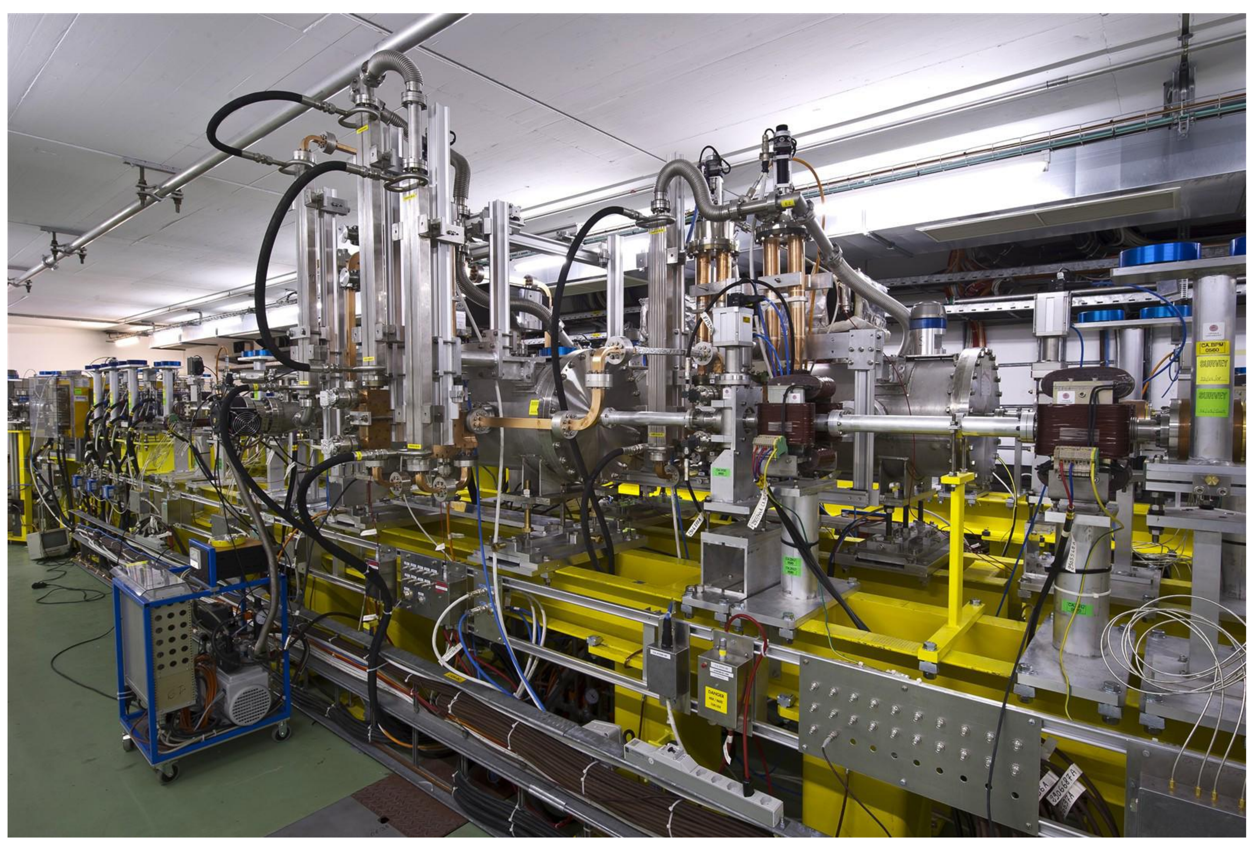
An advanced electro-optic bunch time profile monitor for CLIC (development of novel materials and techniques)

Mateusz Tyrk, Allan Gillespie and Amin Abdolvand

University of Dundee, Dundee DD1 4HN, UK

The Dundee-Daresbury Accelerator Diagnostics Group has world-leading expertise in the measurement of ultra-short electron bunch distributions in particle accelerators and future-generation advanced light sources. Our current state-of-the-art techniques, previously implemented at DESY FLASH, allow the measurement of ~60 femtosecond rms bunch lengths, and developments planned for the CERN CLIC project over the next two years will reduce this measurable bunch length to around 20-30 fs. Future electron and photon sources, especially the laser wakefield accelerators (LWFAs) currently under development in the UK, USA and Germany, among others, will generate bunches in the 1-5 fs regime and even shorter, and therefore new methods need to be devised to characterise such ultra-short bunches with good precision.

Within this project the group is developing novel EO materials in the form of thin film 2D birefringent ‘metamaterials’, artificially produced to yield a high EO coefficient, and structured via laser processing of a suitable substrate. Customisation of the type of structures and manufacturing processes will be required to maximise the EO properties. Laser-processed materials will be produced within the MAPS group at the University of Dundee, then characterised at Dundee and at ASTeC, Daresbury Laboratory. Project activities will include development and testing of the metamaterials, incorporation of these into electro-optic (EO) beam profile monitors at Daresbury, and implementation of these techniques at the CTF3 facility at CERN, PSI Villigen, and other laboratories. We are also collaborators in the Strathclyde University Alpha-X/SCAPA laser plasma wakefield project, and will develop these ultrashort diagnostics for the SCAPA facility.



Califes two-beam test stand

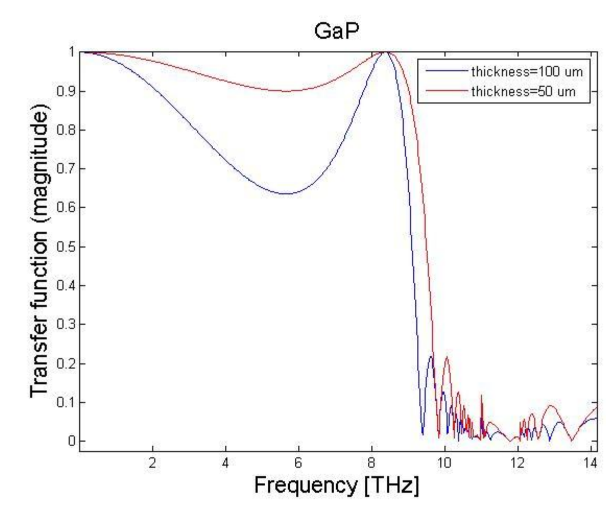
Aims:

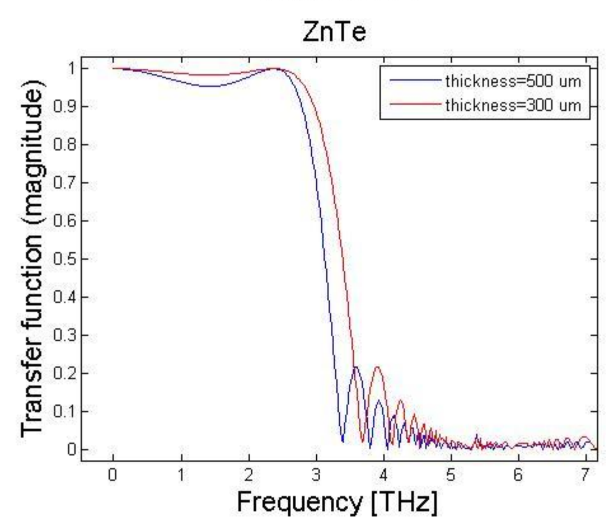
- Resolution measured so far ~60 fs rms
- Planned improvement for CLIC project: 20-30 fs
- Future projections down to - 1-5 fs

Limitations of the currently used materials:

- phase matching
- GVD
- crystal reflection
- phonon resonances
- <u>material frequency response, R(ω)</u>

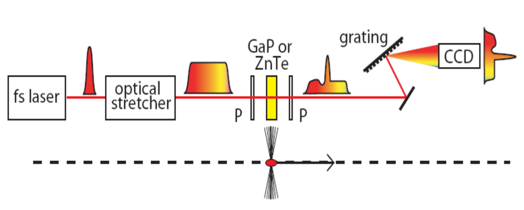
To realise diagnostics for shorter electron bunches we should aim for materials with better frequency response.





Existing electro-optic techniques and their limitations:

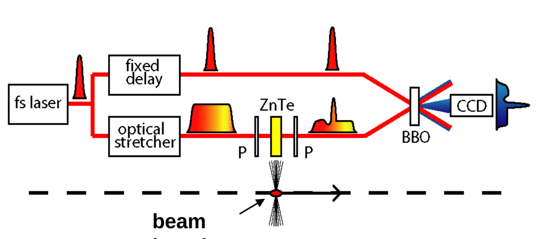
Spectral Decoding



Limitation is ultimately dependent on the probe pulse chirp, and can be shown to be [1]:

$$\tau_{\lim} = \sqrt{12\pi\beta}$$

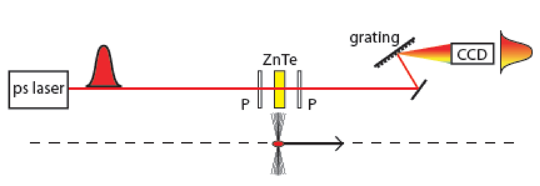
Single-shot Temporal Decoding (EOTD)



Technique limited by

- gate pulse duration. Practical implementation limits gate to >40fs FWHM (laser transport, cross-correlator phase matching/signal levels)
- EO encoding efficiency, phase matching

Electro-optic spectral upconversion



- potential for determining information on even shorter structure - with acceptance of loss of phase information and explicit temporal information at the same time

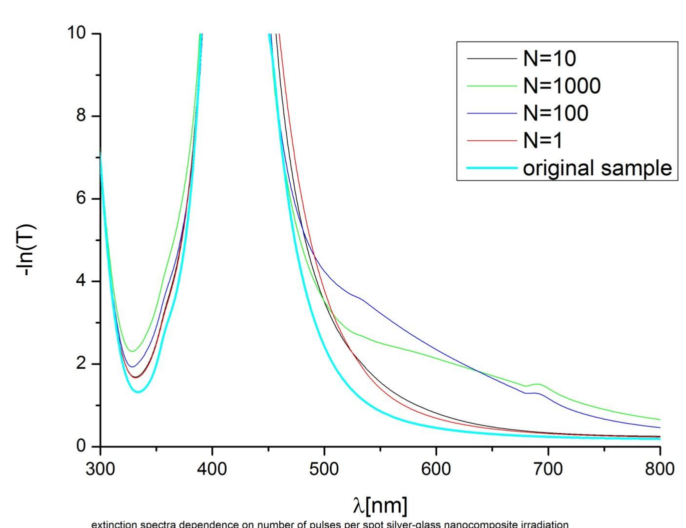
University of Dundee MAPS facility contains state-of-the-art laboratory equipment for novel laser materials processing :

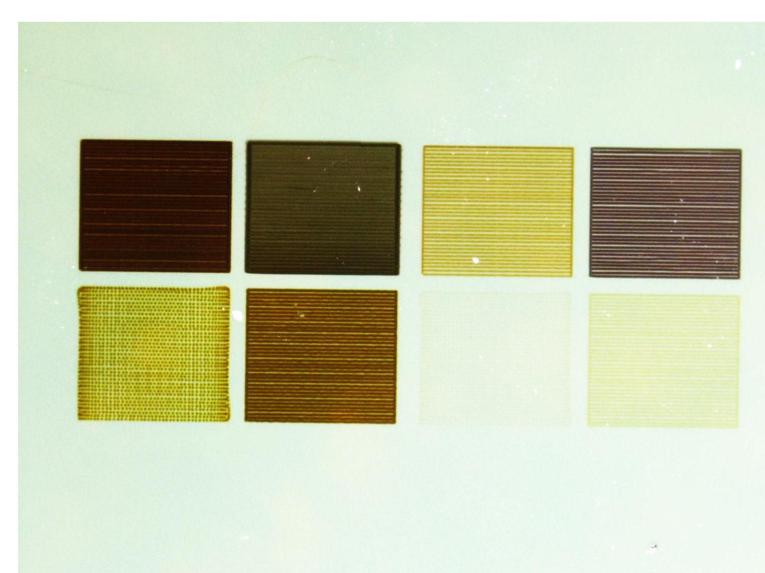
- 3 nanosecond laser systems at wavelengths 355, 532 and 1064 nm in place since 2011
- Picosecond (Coherent Talisker ULTRA 355-04) system installed in May 2012. Operates at same 3 wavelengths, pulse width <15ps with an average power of up to 4W at 355nm, 8W at 532nm, and 16W at 1064nm

[1] S. P. Jamison, G. Berden, W. A. Gillespie, P. J. Phillips, A. M. MacLeod. *Limitations of electro-optic measurements of electron bunch longitudinal profile*. EPAC.?? 1149

Planned improvements of the encoding process:

- Investigation of new electro-optic materials for EO profile systems at CLIC
- Experimental characterization of thin films and meta-materials as novel EO detectors.
- Demonstration of the concept of a multiple crystal detector spanning a wide optical bandwidth





Planned improvements of the decoding process:

- Demonstration of single-shot X-FROG measurements on a laser-generated THz source.
- Demonstration of X-FROG detection on an electron beam source.

STFC Daresbury Laboratory

University of Dundee

LA^{3}NET, 1st Intl School on Laser Applications, GANIL, France, October 2012