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Accelerators in a new light

Experimental demonstration of a continuously tunable terahertz source based on a dielectric wakefield structure

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Outline

- Experimental setup
- Variation of THz pulse energy
- Variation of THz frequency
- Outlook & conclusions

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Continuously tunable narrow-band terahertz generation with a dielectric lined waveguide driven by short electron bunches

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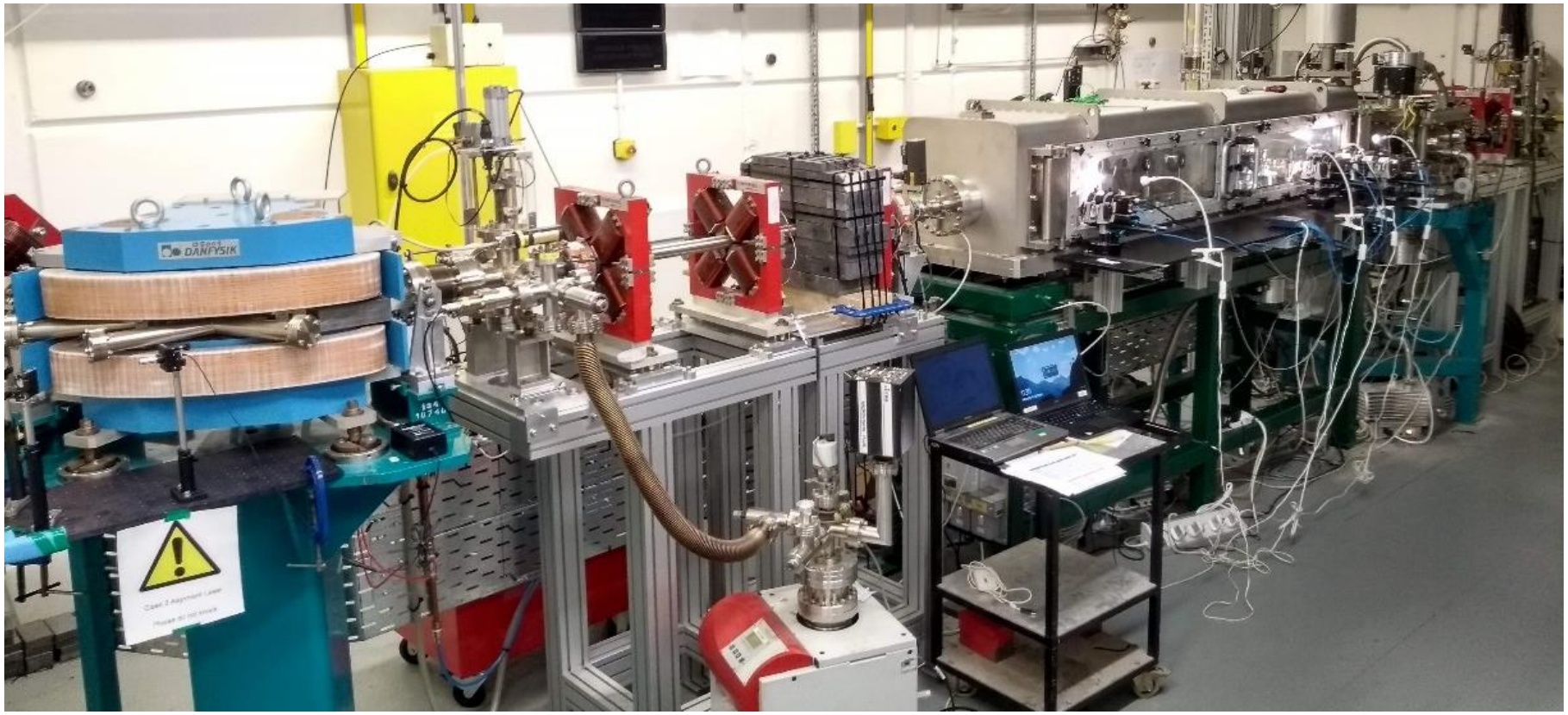
Background

- Studying the radiation generated in a rectangular dielectric wakefield accelerator (DWA)
- This is Coherent Cherenkov radiation (CCR)
- Present in all DWAs – the thicker the dielectric the more multi-mode the spectrum
  - Sub-ps bunch = sub-THz radiation
- Select of waveguide parameters for single mode excitation
- Previous studies have demonstrated stepwise tunablility
  - Tubes of various sizes [1], bunch trains to resonate HOMs [2]
- Aim of this study was continuous tunability by varying the structure gap

[1] A.M. Cook et. al., PRL 2009
[2] G Andonian, et. al., APL 2011

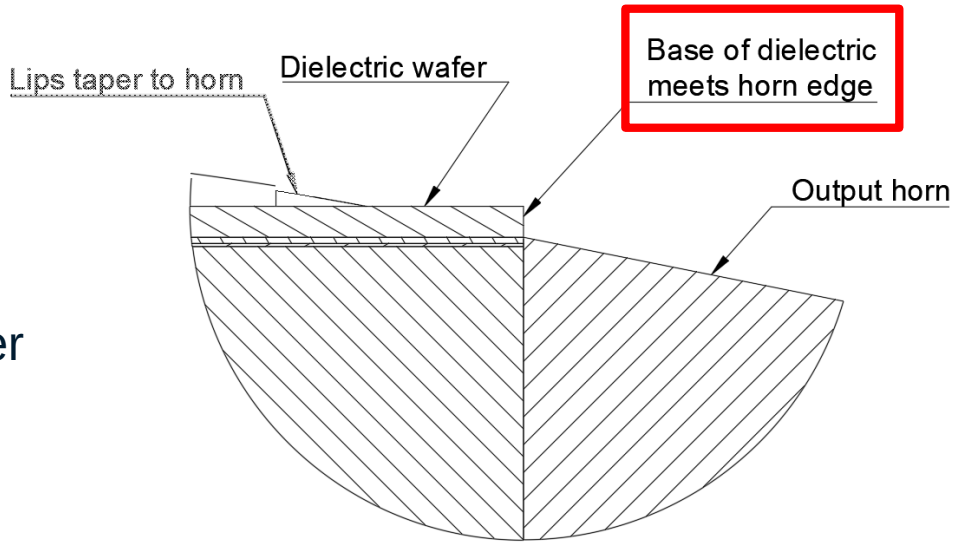
CLARA/VELA BA1



- Experimental area for variety of experiments, including novel acceleration
- On VELA line, fed by CLARA front-end via dog-leg -> sub-ps bunches
- See slides in previous talk by Y. Saveliev

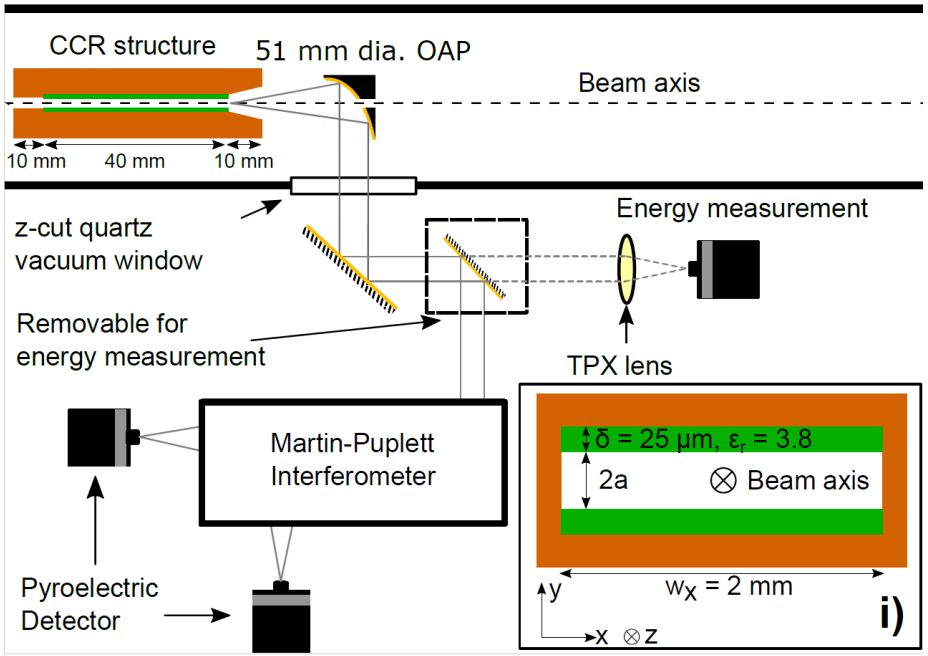
Beam parameters and & DLW design

Parameter	Symbol	Value
Energy	E	35 MeV
Charge	Q	70 pC
RMS horiz.	σ_x	150 μm
RMS vert.	σ_y	70 μm
RMS length	σ_t	0.3 ps
Width	w_x	2 mm
Length	L_{str}	40 mm
Dielectric thickness	**δ**	**25 μm**

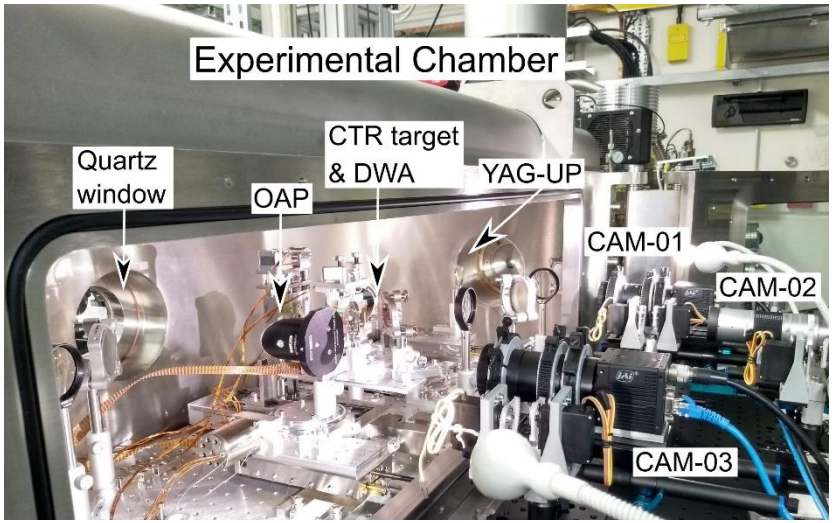


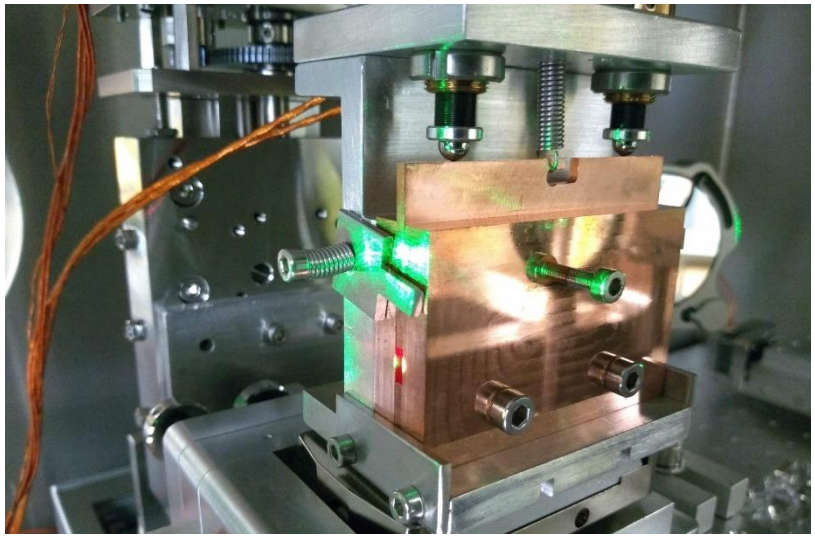
- Thin dielectric layer for tunability
- Base of dielectric must meet coupler horn
- Manufacture from quartz wafers is non-trivial!

Experimental Setup



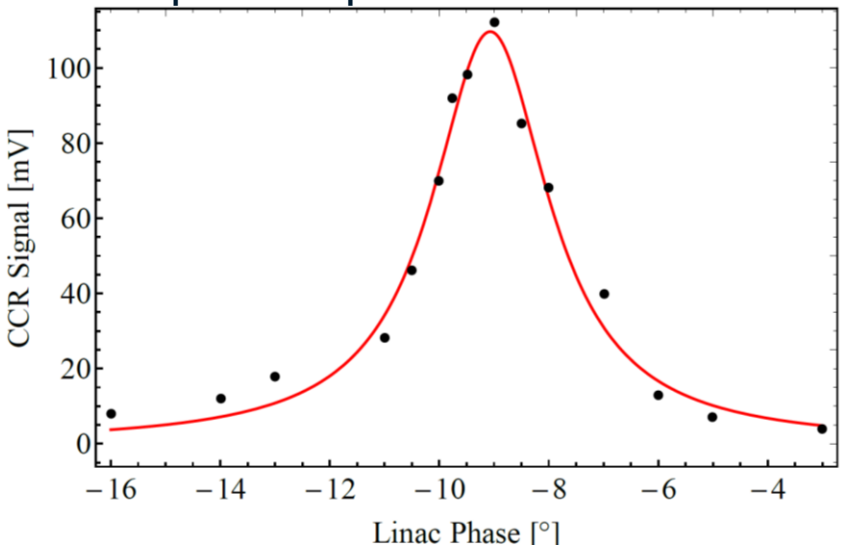
- Bespoke THz diagnostic system
- 3x Pyroelectric detectors used
- Measurements of RMS bunch length via CTR spectrum
- Structure gap varied with picomotors, precision ±20μm
- Cameras used to view structure gap



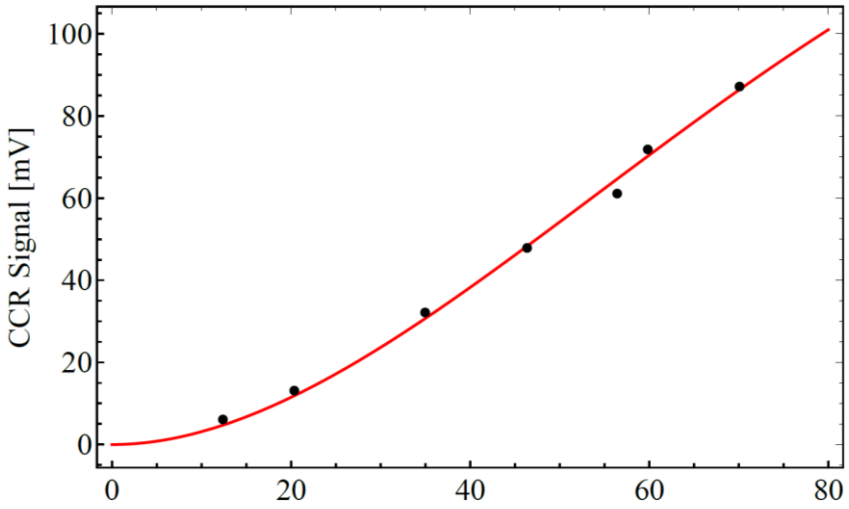


Variation of CCR pulse energy (1)

Gap = 540 µm



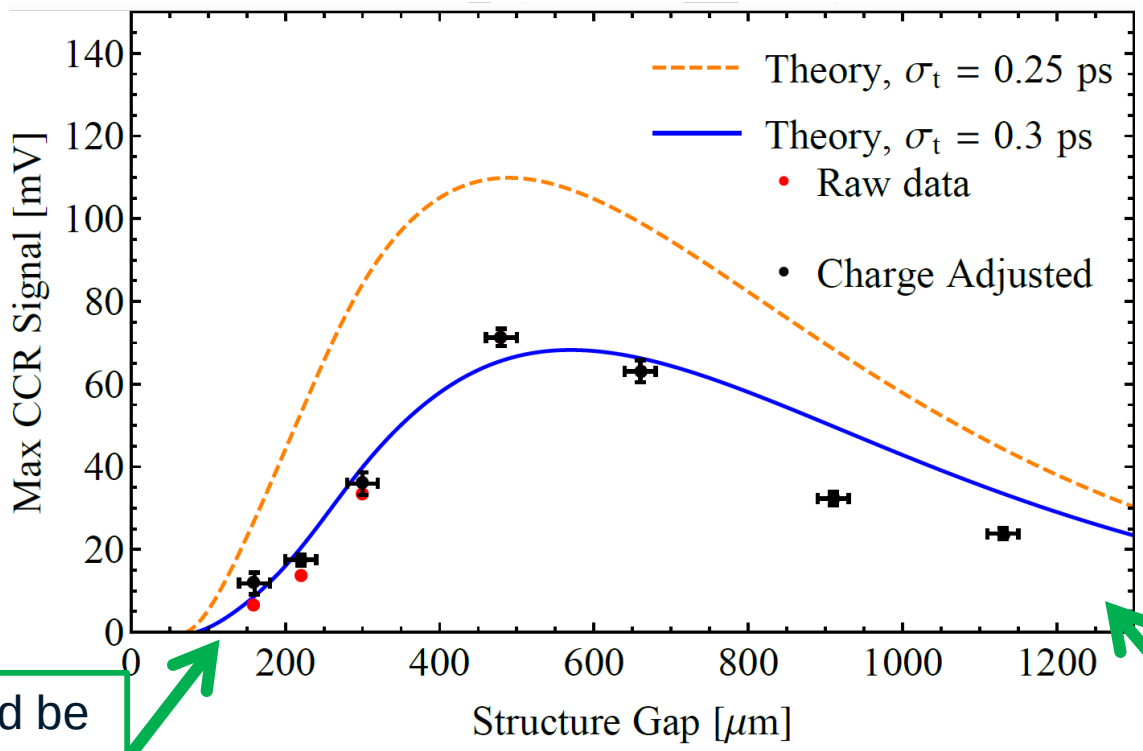
- Energy increases at maximum compression
- Rapidly falls away from compression
- Calibrating the pyroelectric detectors gives maximum pulse energy of ≈0.6 µJ



Gap = 590 µm

- Quasi-quadratic fit with charge
- $I \propto Q^2 |F(\sigma_t)|^2$
- Assume Gaussian longitudinal profile
- $F(\sigma_t) \rightarrow F(\sigma_t, Q)$
- Vary σ_t linearly from 0.25ps to 0.30ps with Q

Variation of CCR pulse energy (2)



- Field should be be increasing
- But frequency is increasing
- Bunch coupling reduces
- Overall decrease

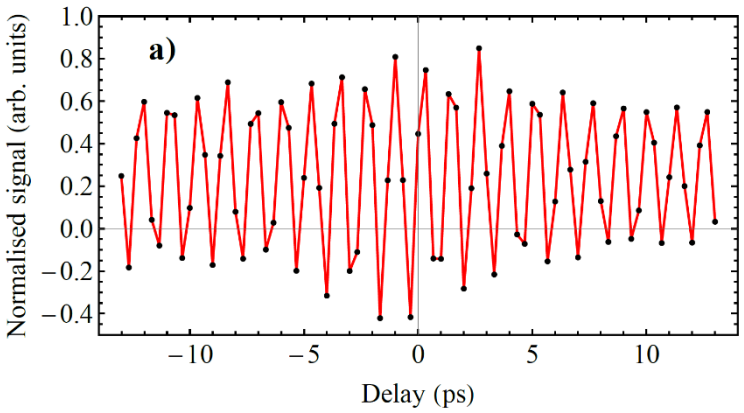
Theory calculated from normalised Poynting vector from [3] using a Gaussian bunch

- Field strength is decreasing
- Frequency isn't changed significantly

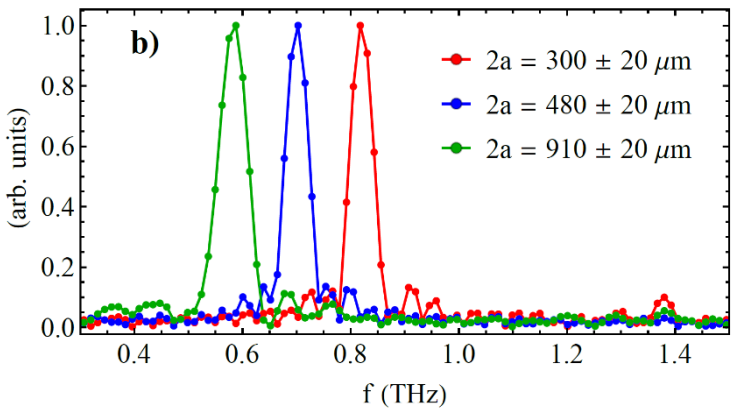
[3] D. Mihalcea, et. al., PRSTAB, 2012

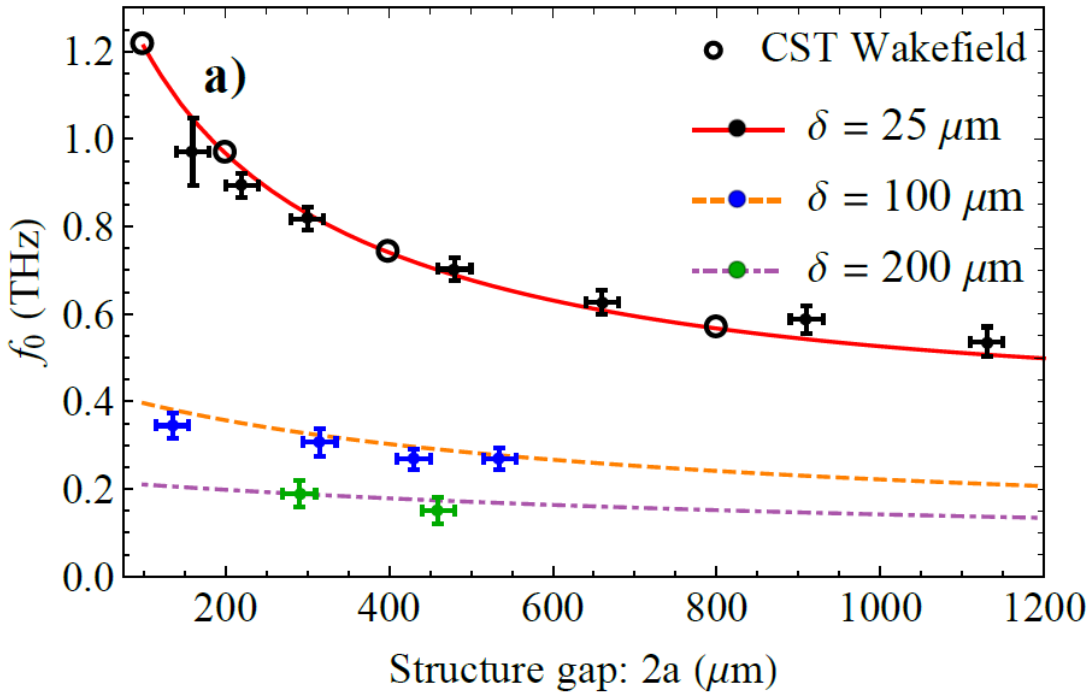
Variation of CCR frequency with gap

- Interferogram for 300 µm



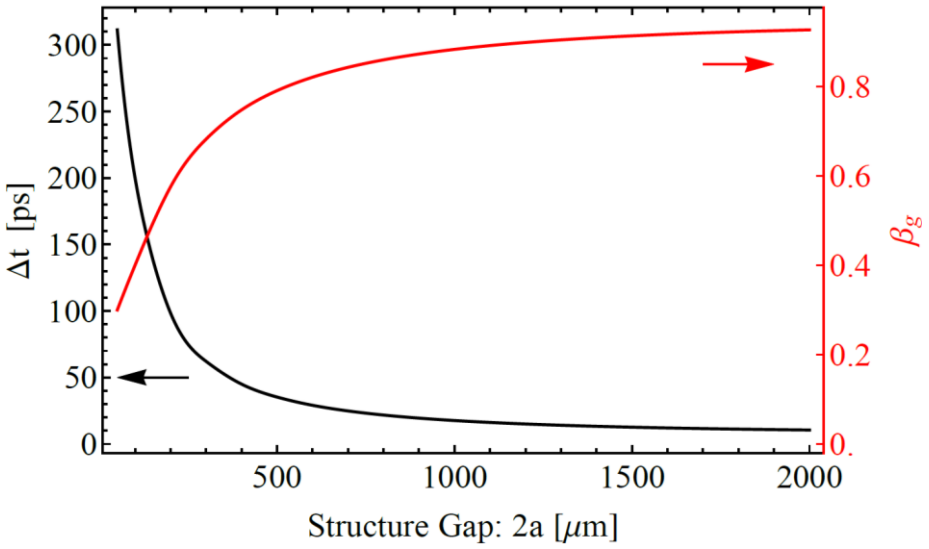
- CCR spectra

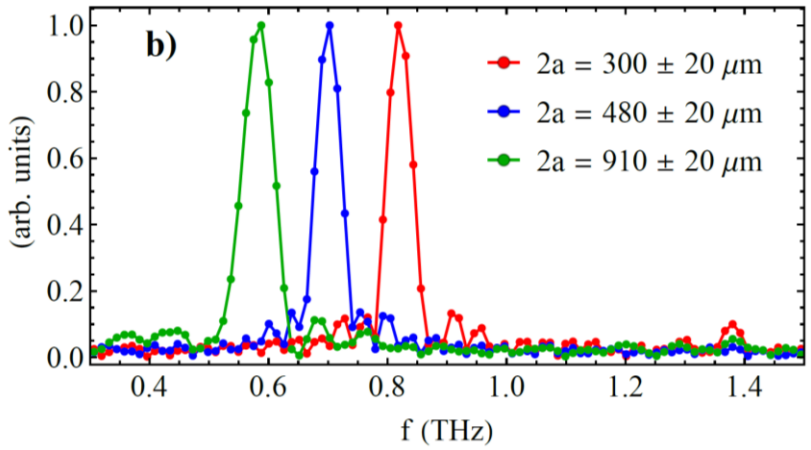




- Agreement with simulations, and analytical calculations [3]
- 25µm thickness tunes from 0.95 to 0.55 THz
- Error bars = FWHM spectrum
- Also studied thicker dielectric layers (previous talk by Y Saveliev)

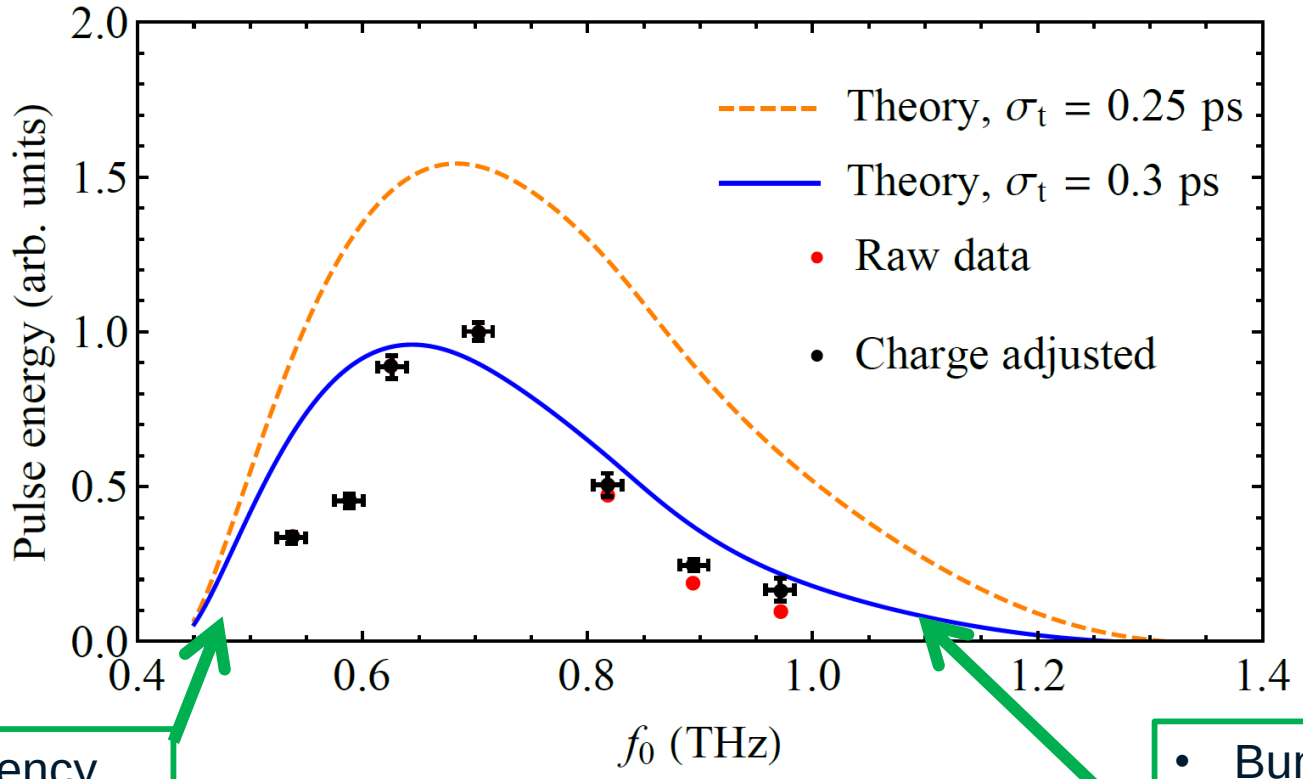
CCR pulse bandwidth





- Theory predicts variation of group velocity (β_g) with structure gap
- Therefore pulse length should also change
- $\Delta t = L_{str}\ \frac{1-\beta_g}{\beta_g\, c}$
- Did not observe as limited by interferogram scan length
- All bandwidths FWHM in range ≈50 GHz
- Minimum BW would be limited in reality by dielectric absorption, dispersion etc.

Variation of pulse energy with frequency

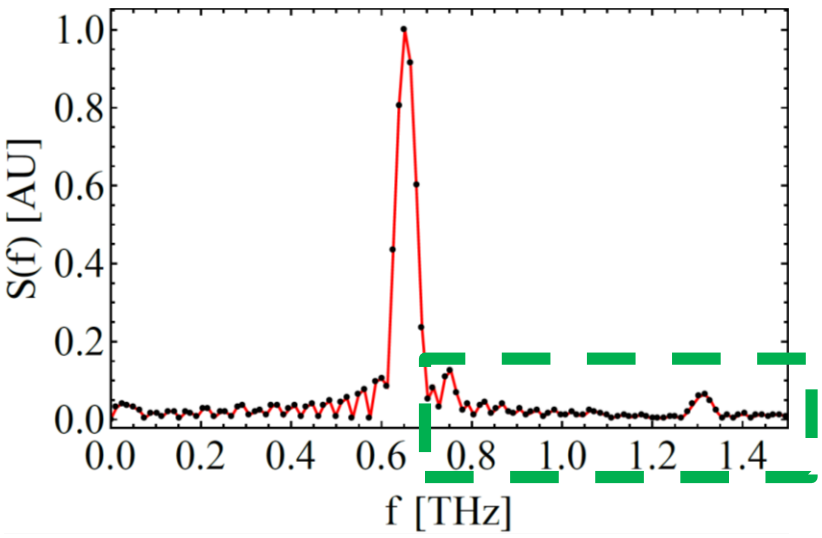


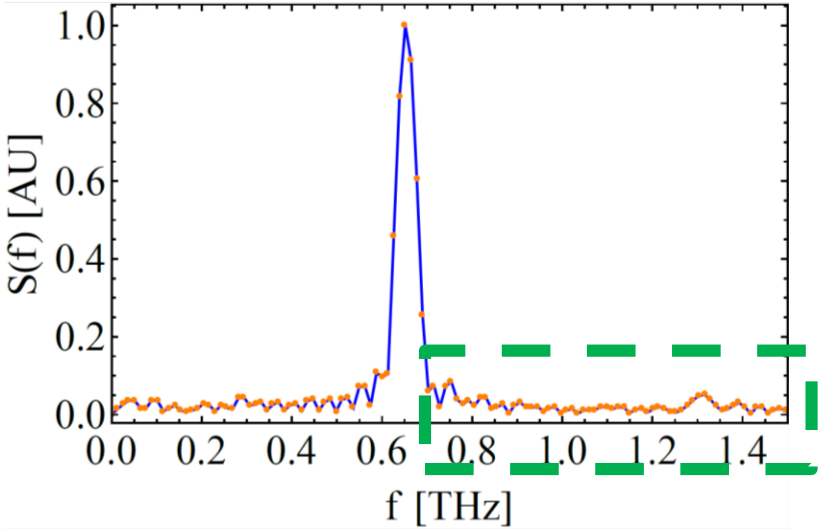
- Frequency doesn't change
- Field just decreases

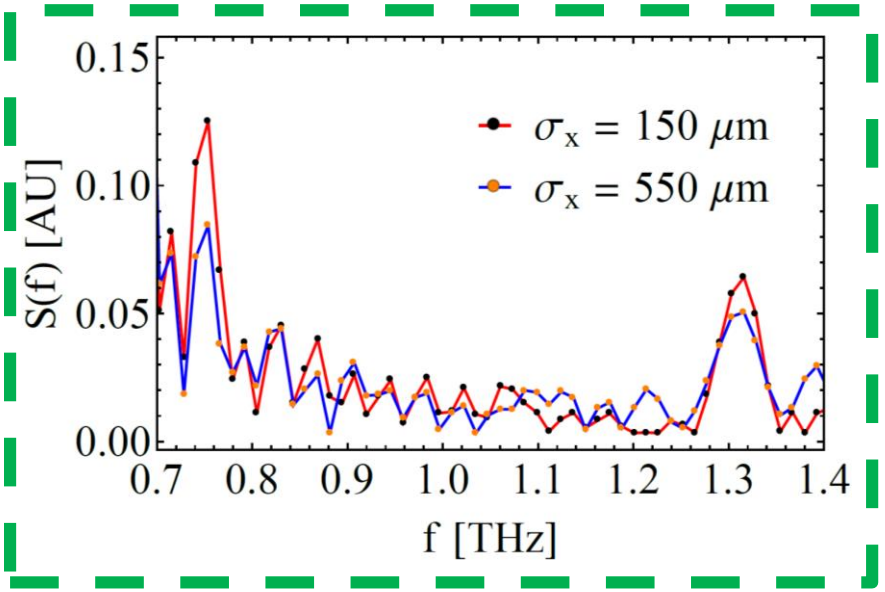
Use measured frequencies for data
Map theory from gaps to frequency

- Bunch coupling reduces
- Decreasing bunch length benefits greatly

Excitation of HOMs



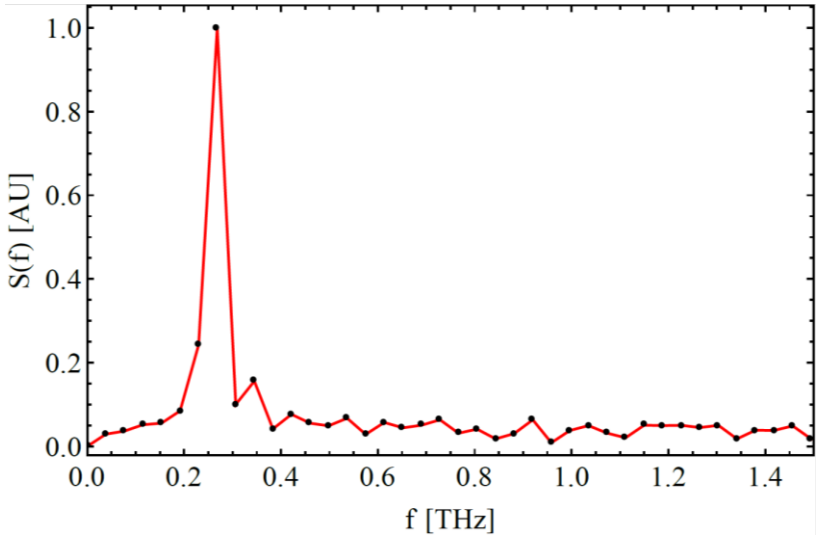




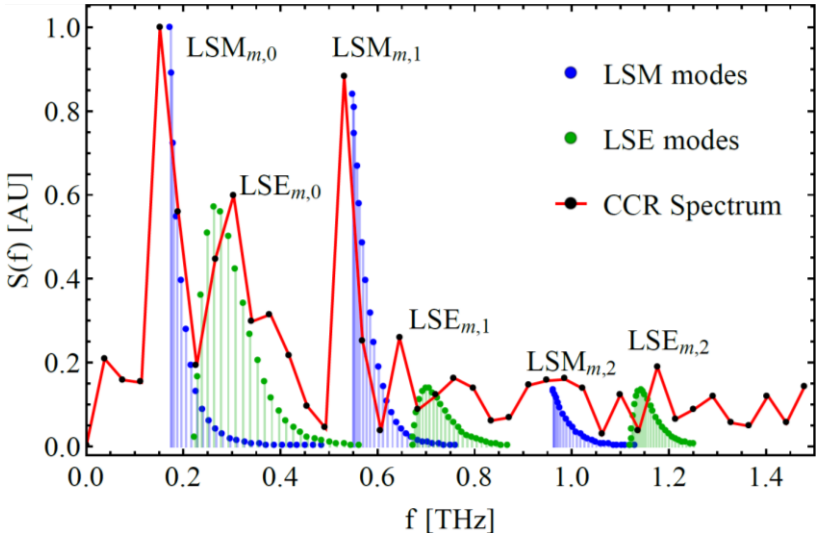
- Weak excitation of HOMs
- Maybe some decrease as bunch aspect ratio increased
- Dominated by single fundamental mode

HOMs in thicker dielectric structures

δ = 100 μm Gap = 540 μm



- 100 μm thick dielectric still quasi-single moded
- With reduced tunability, 0.3 – 0.4 THz



- 200 μm thick dielectric highly multi-moded
- Further reduced tunability, 0.15 – 0.2 THz
- Qualitative agreement with theory for variety of modes

δ = 200 μm Gap = 460 μm

Outlook

- Higher charges (200 pC +) and shorter bunch (~100 fs) would produce 10s µJ level source
- This highly compact source which would integrate well into ‘table-top’ accelerator systems
- LWFA systems already producing the short bunches required, clear potential synergy
- Intrinsic synchronisation with the beam benefits pump-probe type experiments
- Ultrashort bunches and/or bunch trains could hit HOMs >3 THz

Conclusions

- Demonstrated continuously tunable CCR across band 0.55 – 0.95 THz using variable gap DWA with thin dielectric layer
- Single mode operation with negligible excitation of HOMs
- Estimate pulse energy of 0.6 μJ from only 70 pC bunch, at frequency of 0.65 THz
- Verified analytical models of DWA across a wide range of experimental parameters
- Stepping stone towards future UK DWA experiments