Laser-driven
Terahertz frequency transverse deflectors (?)

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Light sources requirements for ultrashort bunches

Push for ultra short, sub 10fs, bunches

LCLS: ~200 fs bunches @ 200 pC
<10fs @ 10 pC
optical (~1fs) structure

FLASH: ~300 fs bunches post-upgrade
<100 fs pre-upgrade
~10 fs micro-bunching structure

NLS design: ~200 fs nominal
<10 fs low charge mode

Swiss-FEL: < 10 fs

laser-plasma wakefield: < 10 fs ?
< 1fs ?

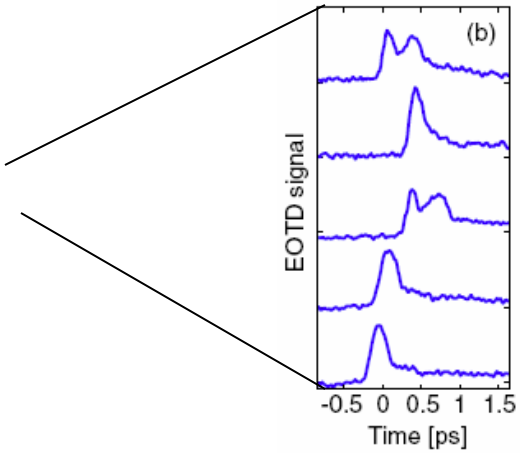
FACET: ~ 60 fs rms

Ultrafast bunch diagnostics

Bunch profile diagnostics

Electro-optic: ~100fs fwhm structure resolved

concepts for >50fs demonstrated



Radiative diagnostics (CSR, CDR, CTR, ...)

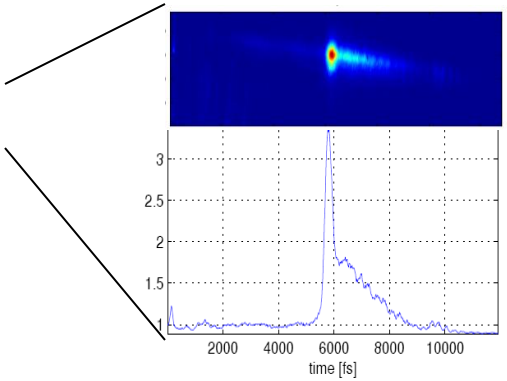
single shot F-IR to mid-IR demonstrated

empirical information only (reconstruction?)

RF zero-crossing: ~50fs FWHM observed at DUVFEL

Deflecting cavity: demonstrated ~15 fs rms (FLASH)

few fs (LCLS..."upper bound")



Slice diagnostics

Deflecting cavities....

limited to >10fs for slice energy

Deflecting cavity time resolution

Deflection

$$\Delta x'(z) = \frac{eV_0}{pc}\sin(kz+\varphi) \approx \frac{eV_0}{p_z c}\left[\frac{2\pi}{\lambda} z\cos\varphi + \sin\varphi\right]$$

Observed streak...

$$\Delta x(z) \approx \frac{eV_0}{pc}\sqrt{\beta_d \beta_s}\,\sin\Delta\psi\left(\frac{2\pi}{\lambda} z\cos\varphi + \sin\varphi\right)$$

temporal resolution limit: streak Δx^{screen} > σ_x^{screen}

improvements...

- higher deflection voltages
- smaller emittance, larger cavity β_d
- *shorter wavelengths*

X-band $\Rightarrow$ 1 THz ... 10^2 reduction in wavelength

$\Rightarrow$ optical (~400 THz) ... 4×10^4 reduction

Laser driven THz sources...

Photo-conductive antenna..

- High bias on insulator (e.g. unilluminated semiconductor GaAs)
- fast transition to conductor by ultrafast (~50fs) laser pulse
- sub-ps current surge radiates THz pulse (very large $\partial \mathbf{J}/\partial t$)

highest laser-> THz efficiency

1μJ energy possible from simple antenna and 1mJ, 50fs laser system

Frequency mixing & "optical rectification"

2-frequency difference mixing $E(\omega) = \chi^{(2)} E_1(\omega-\omega')E_2(\omega')$

mono-chromatic THz

broadband self mixing $E(\omega) = \chi^{(2)} \int E_1(\omega-\omega')E_1(\omega')$

THz field following laser pulse envelope

High power laser driven THz sources

“long” pulse

Frequency mixing...UCLA, CO_2 laser (Inverse FEL experiments)

huge laser infrastructure

“short” pulse

Ultrafast optical rectification

- table-top Ti:S lasers producing ~10 μJ, ~1 ps, THz pulses....
- scalable...?
- > 100 MV/cm reported, but at 20 THz
- Single-cycle pulses, optical->THz pulse shaping possible

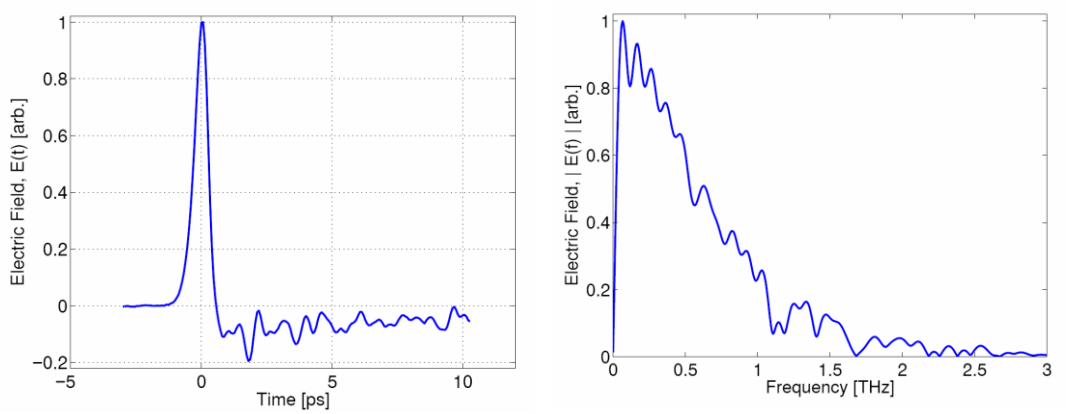
Ultrafast antenna / current surge

- Table-top Ti:S lasers producing few-μJ, ~1ps, THz pulses.
- Scalable.
- Single-cycle and quasi-monochromatic possible

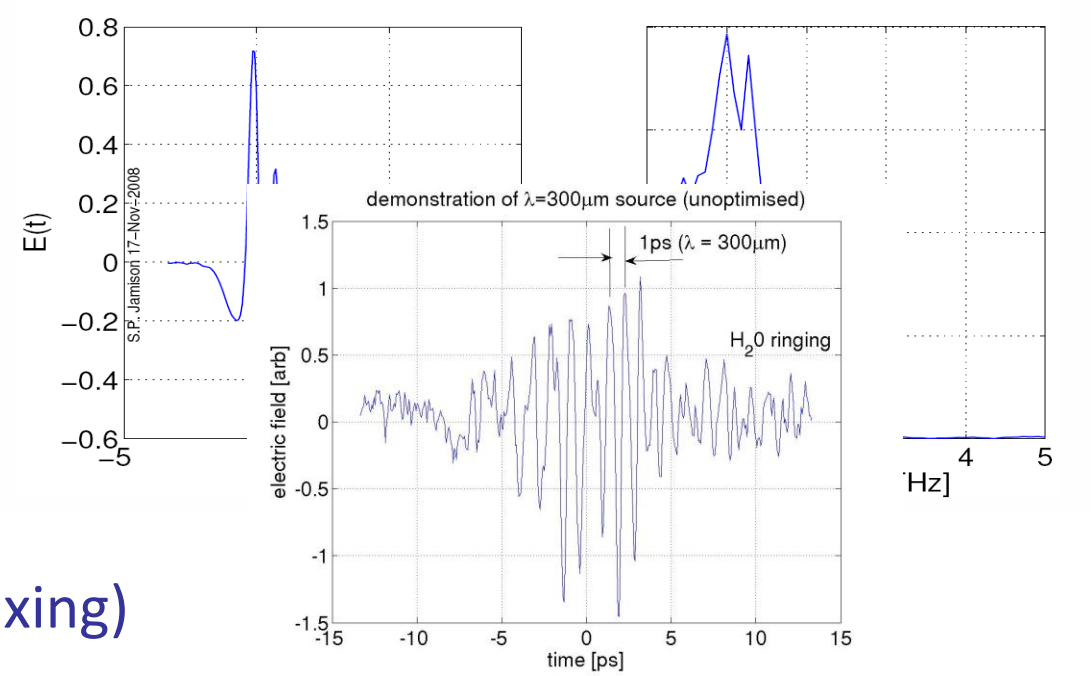
MV/m fields readily available - *in free space*

laser driven THz sources in ALICE lab

High power antenna...



optical rectification...

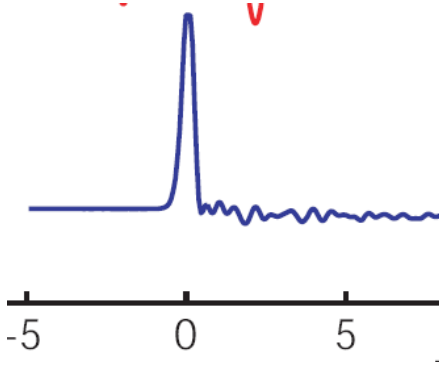


quasi-CW (frequency mixing)

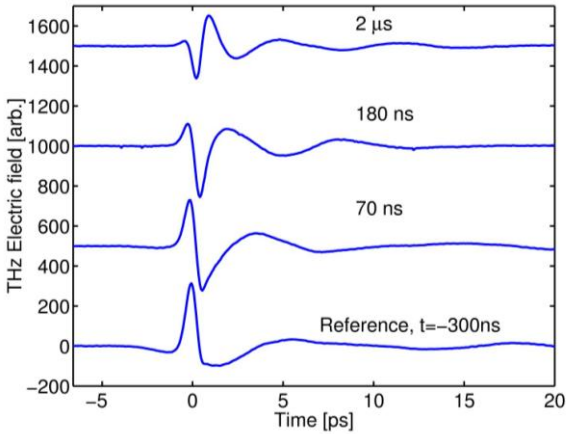
“single-cycle” pulse shape evolution

complication & a possible tool

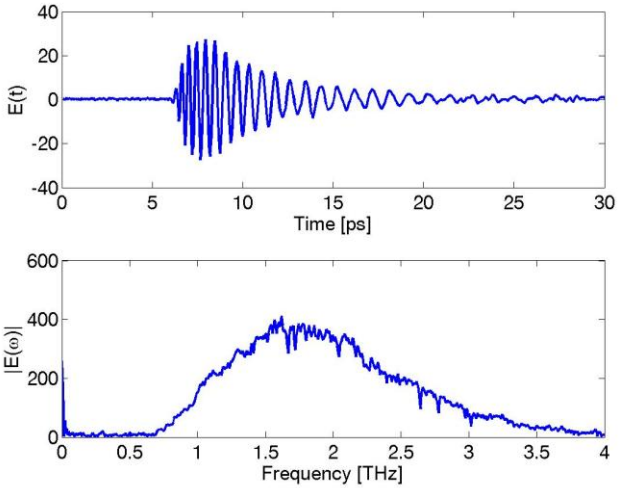
Near field uni-polar pulse

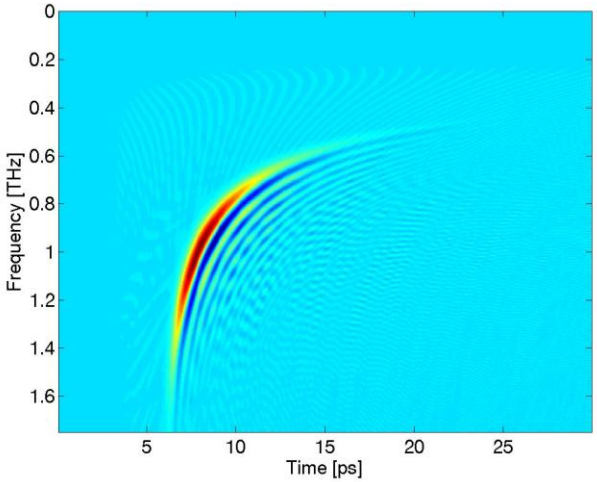


propagation through plasma medium



waveguide dispersion



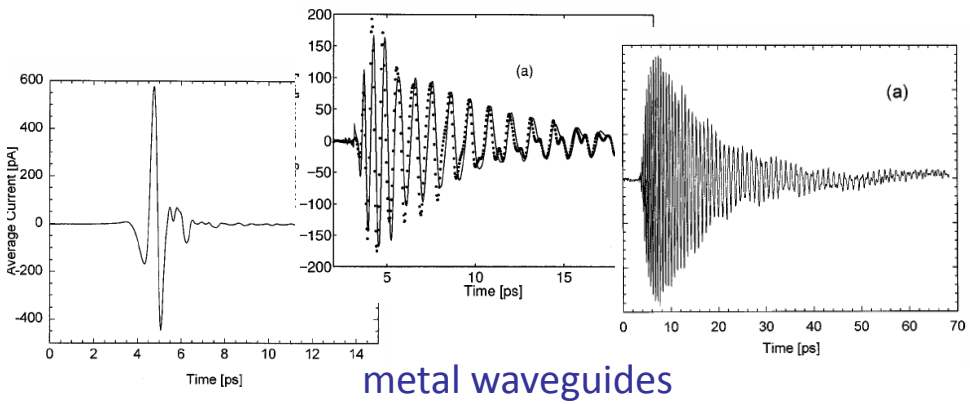


...mode dispersion can be observed directly

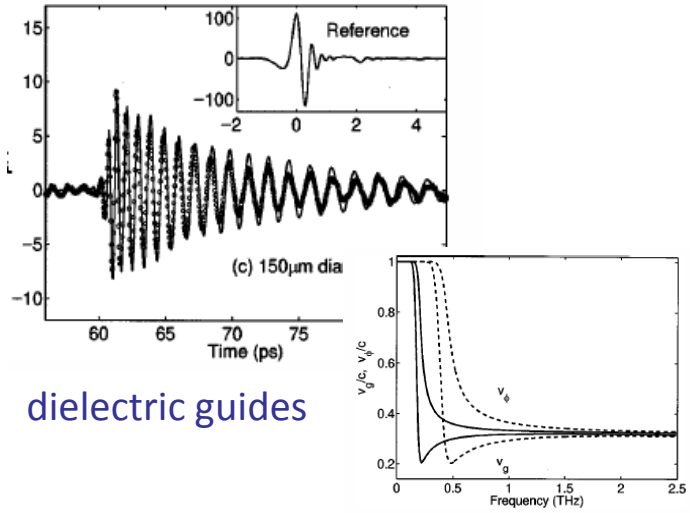
Coupling to waveguide structures...

THz coupling to sub-mm structures `routine`

- Gallot, ... Jamison, et al JOSA-B (2000) [metallic waveguides]
- Jamison et al, Appl Phys Lett (2000) [dielectric fibres]
- ....now many examples..



metal waveguides



dielectric guides

More recent DL activity: coupling to few-mm waveguides for material characterisation (D. Scott et al, PAC 2009)

so far, no attempt to find deflecting or beam phase matched structure

Transverse mode structure

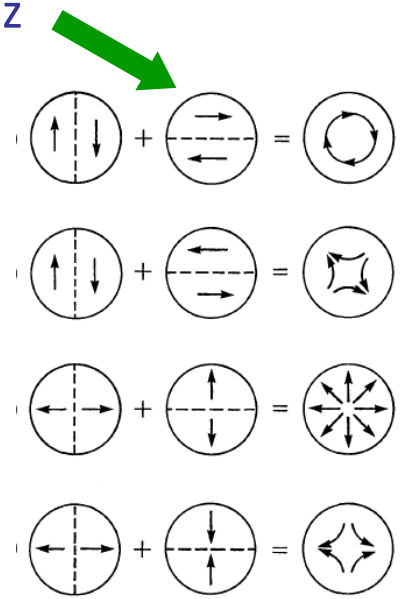
usually generated in linear polarised TEM_{00}
(Gaussian free-space modes)

alternative modes possible through
- interferometric superposition of THz
- source configuration

shaped antenna electrodes

method being examined at Daresbury

non-linear crystal mossaic



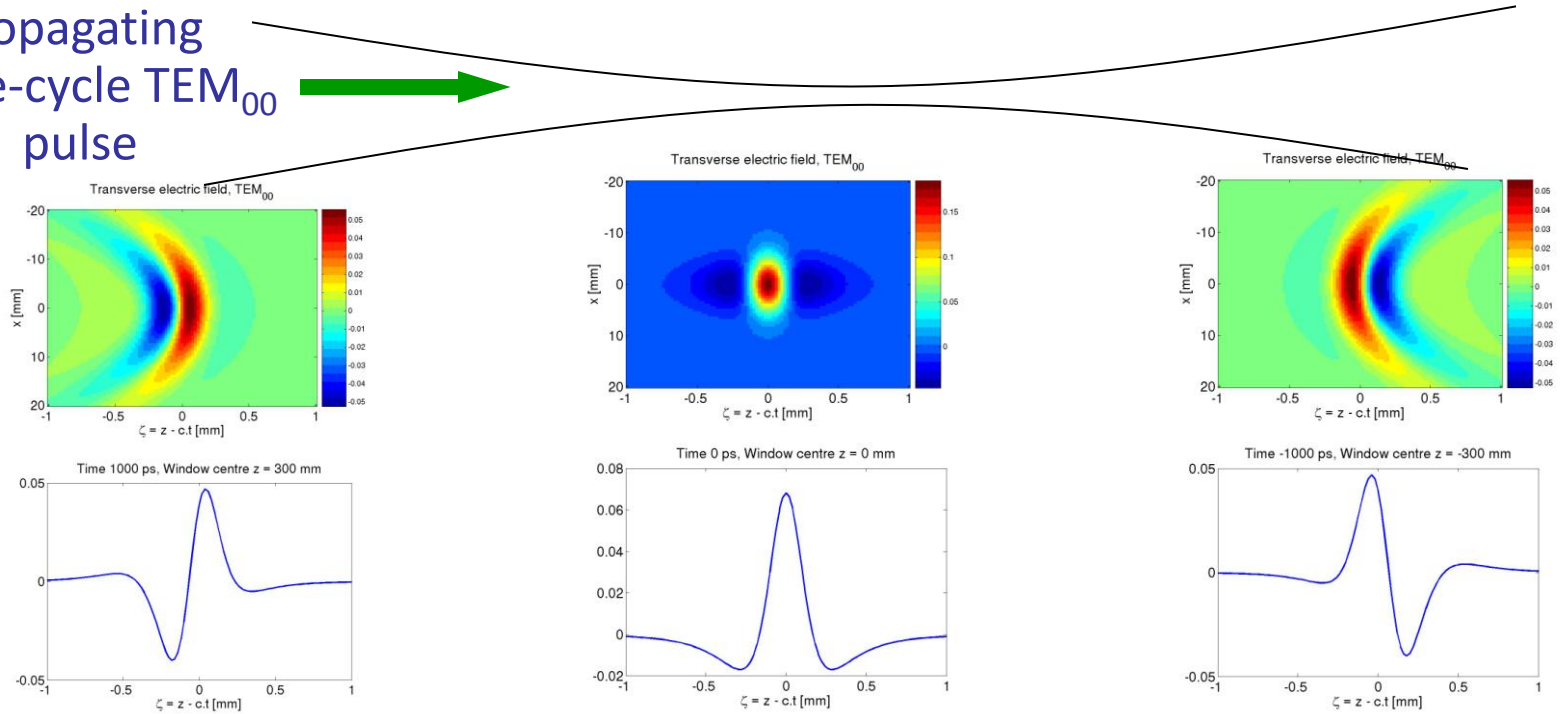
widely demonstrated at optical frequencies, but not yet applied to THz

An Intermediate demonstration...

Free space deflection / *phase space manipulation*.

- picosecond duration ⇒ phase slippage problem less severe than for optical
- non-intuitive phase front propagation for “single-cycle” pulses

propagating single-cycle TEM_{00} pulse



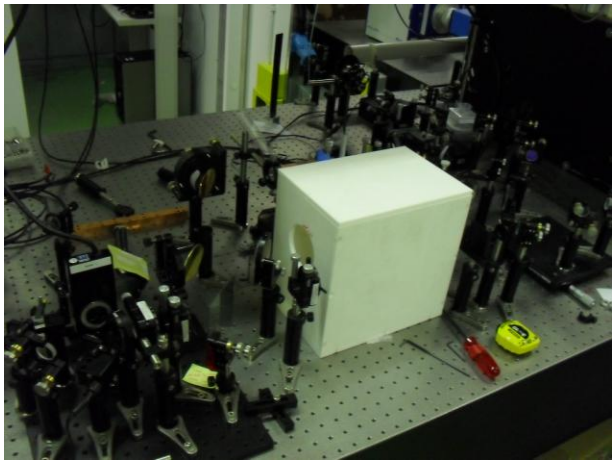
Note polarity reversal through focus! need to break symmetry

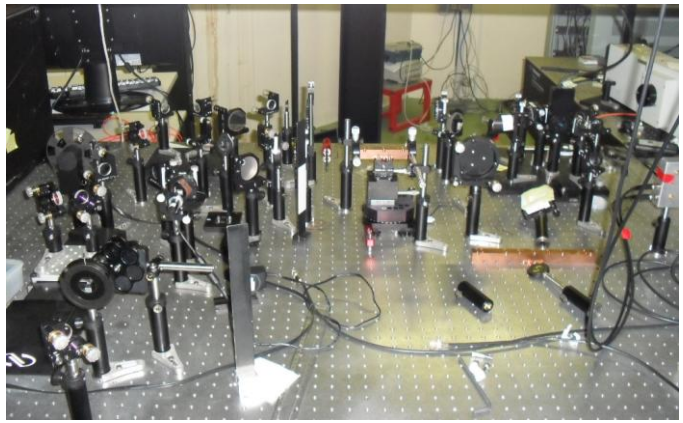
current emphasis:

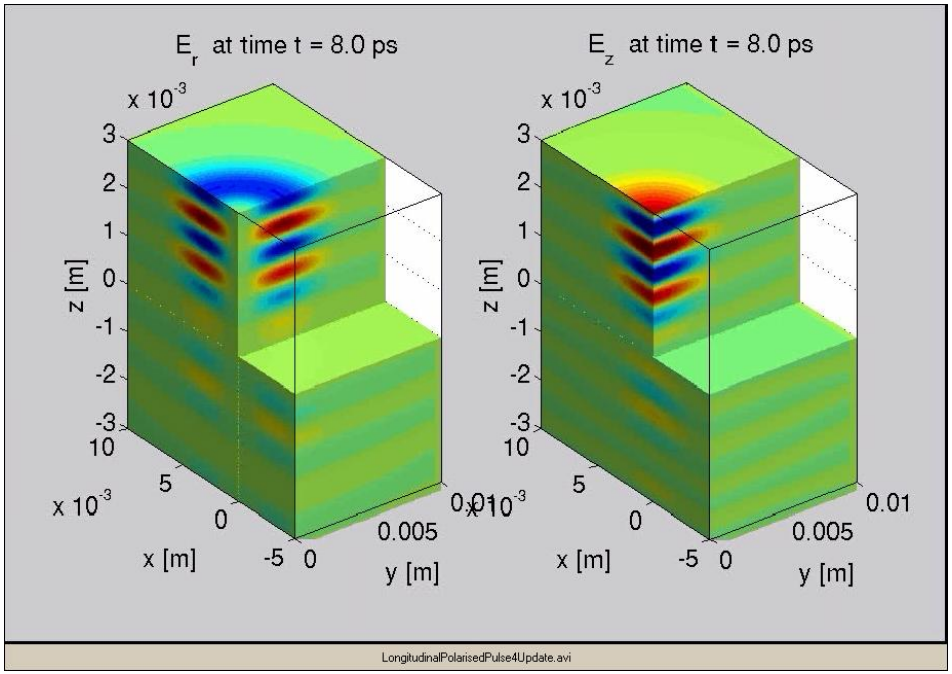
radially polarised THz pulse for energy manipulation

developing radially polarised high field THz source

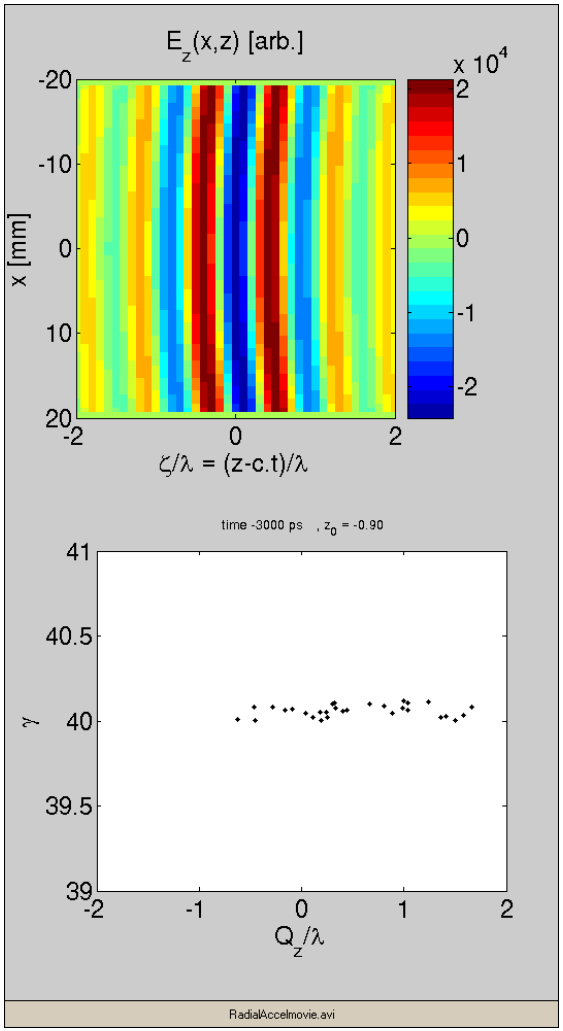
- goal of longitudinal fields $E_z(t_{peak})$ = 10^6-10^7 V/m







Single particle tracking in radially polarised free-space field



Longitudinal electric field (moving window)

particle energy

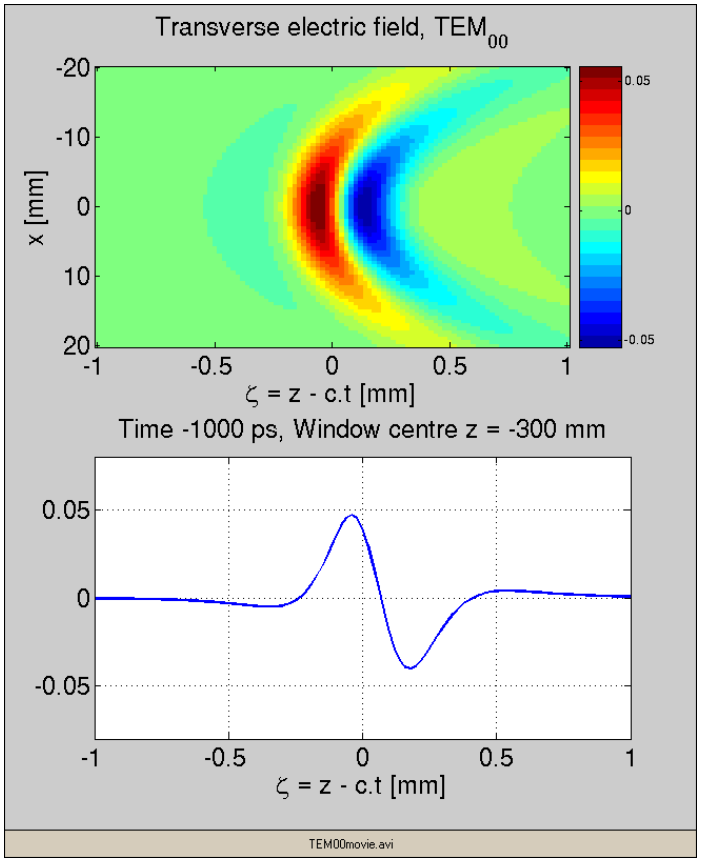
- no radiation depletion or back-reaction
- Interaction stopped at focal position, to halt reversal of energy gain/loss
- In practise, can be accomplished with THz diffracting aperture

Working towards ALICE beam expts...

Could be adapted to deflection ***if*** suitable modes / structures identified

Summary

- Femtosecond beam diagnostics will require higher frequency deflectors
- High field strength THz sources feasible & partially demonstrated
- THz waveguide coupling possible
- ?? are suitable deflecting structures & modes feasible ??
- ?? wakefields ??


Transverse electric field, TEM00
-20
-10
0
10
20
x [mm]
-1
-0.5
0
0.5
1
ζ = z - c.t [mm]
0.05
0
-0.05
Time -1000 ps, Window centre z = -300 mm
0.05
0
-0.05
-1
-0.5
0
0.5
1
ζ = z - c.t [mm]
TEM00movie.avi