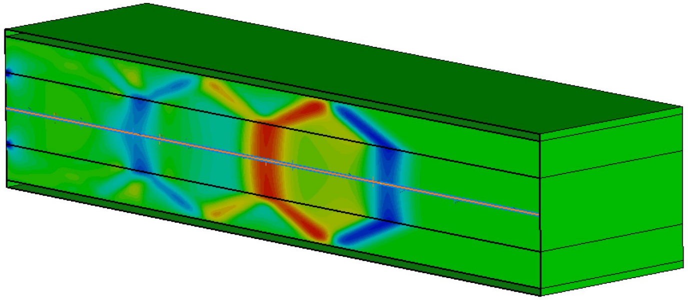
Designing tunable dielectric wakefield accelerators

Thomas Pacey
G. Xia, Y. Saveliev

LA^{3}NET Workshop on Novel Acceleration, Oct. 2016

The Cockcroft Institute of Accelerator Science and Technology

MANCHESTER 1824 The University of Manchester



Outline

1. Motivation & Applications
2. Theory Overview
3. Experimental Plans
4. Achieving tunability vs. Field strength
5. Using Impact-T
6. Dechirping with Impact-T
7. Future work

Motivation & Applications

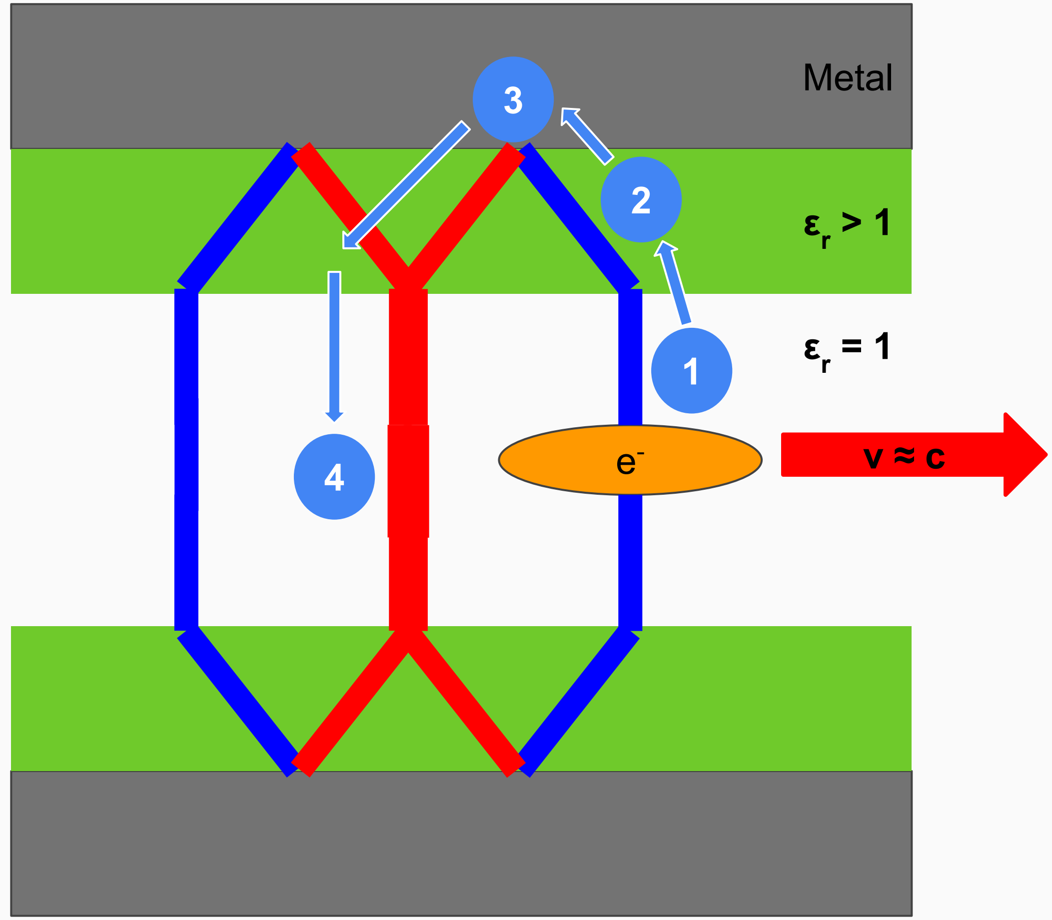
- High frequency and high strength electric fields, and accelerating gradients
- ‘Passive’ component, no external lasers or gases required
- Now seen SiO_2 cylinders drive 320 MV/m accelerating gradients [1]

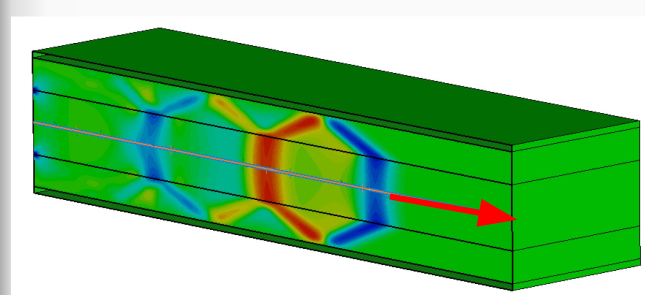
- Manipulate the bunch, including removal of correlated energy spread (dechirping)
- Understand bunch charge limitations in small scale (externally driven) dielectric waveguides

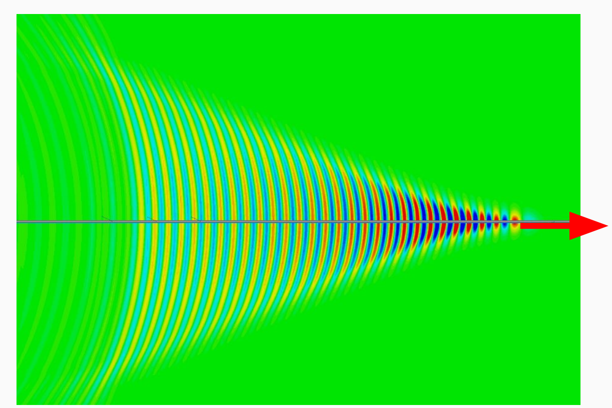
[1] O’Shea, B. D., et al. "Observation of acceleration and deceleration in gigaelectron-volt-per-metre gradient dielectric wakefield accelerators." *Nature Communications* 7 (2016)

Theory overview

1) Relativistic electron bunch with ‘pancake’ electric field
2) Image charge created in dielectric, cannot propagate at c due to $\varepsilon_r > 1$
3) The field is reflected at the metal layer
4) The field is coupled back to the vacuum behind the drive bunch, with a sign shift



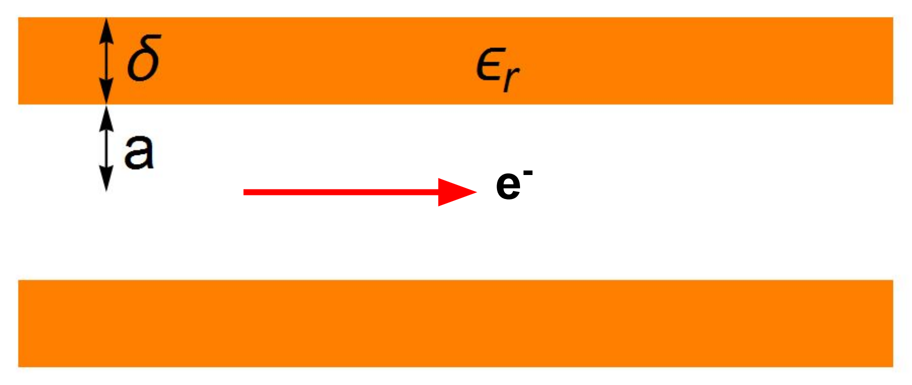




Experimental Plans

- 45 MeV, 250 pC bunch from CLARA/VELA accelerator at Daresbury
- Dog-leg compression could give bunches down to σ_z = 50 μm
- No drive-witness acceleration studies

- Focus on head-tail acceleration studies
- Will be able to vary transverse bunch profile
  - Implications for stability of bunch
- Collect and characterise the THz radiation produced in the structure
  - Aiming for high tunability



Notation and dielectric

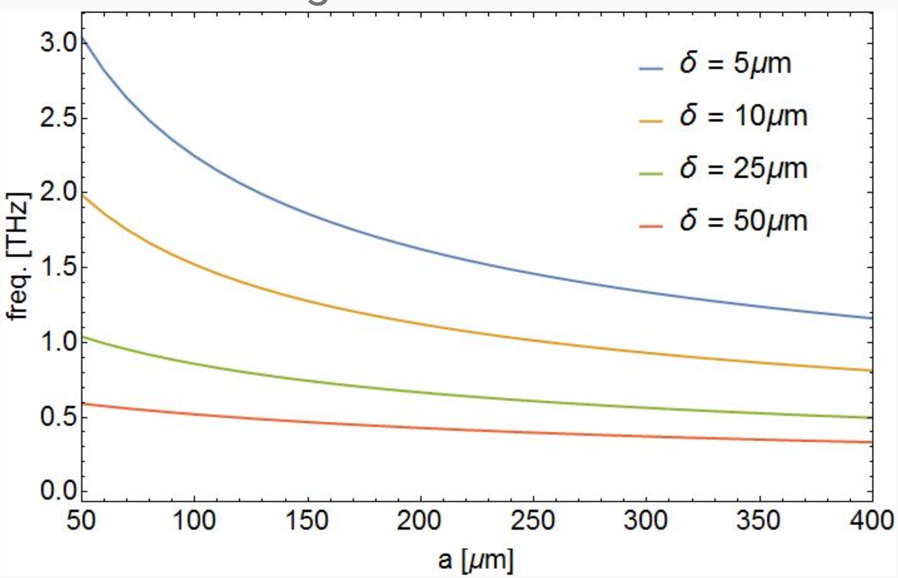
- Chemical Vapour Deposition (CVD) Diamond for the dielectric layers.
- Ideal material: high thermal conductivity, low loss tangent at THz frequencies, and can be deposited in thin layers
- For all cases ε_r = 5.68 and does not vary with frequency

Achieving tunability vs. field strength

2D Analytics - Developed from [2]

Thin dielectric layer gives most tunability.

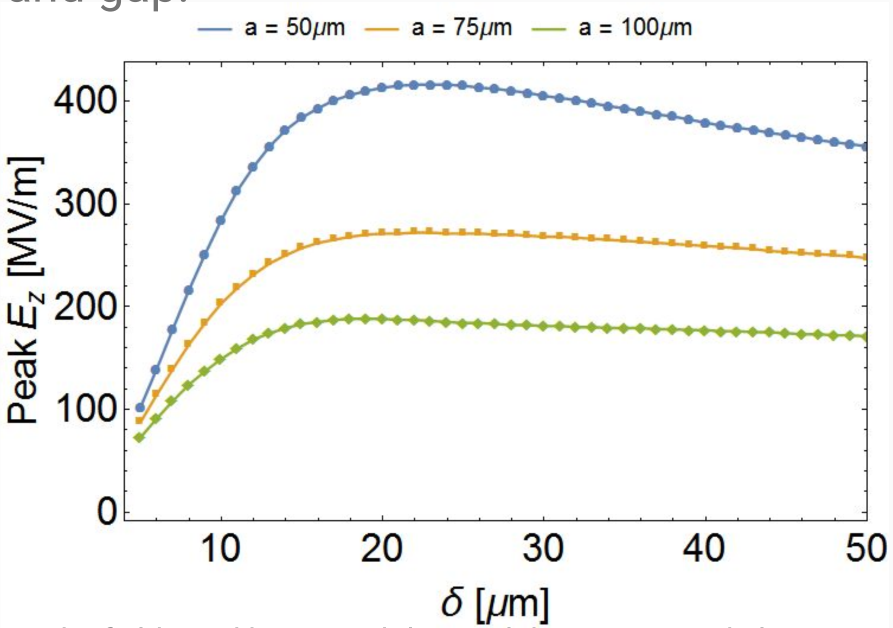
Thin layer means more dependent on waveguide size and less on Cherenkov interaction region.



3D Treatment in CST

Wake spreads transversely as it propagates.

Field magnitude is dependent on thickness and gap.



[2] Tremaine, A., J. Rosenzweig, and P. Schoessow. "Electromagnetic wake fields and beam stability in slab-symmetric dielectric structures." *Physical Review E* 56.6 (1997): 7204.

Using Impact-T

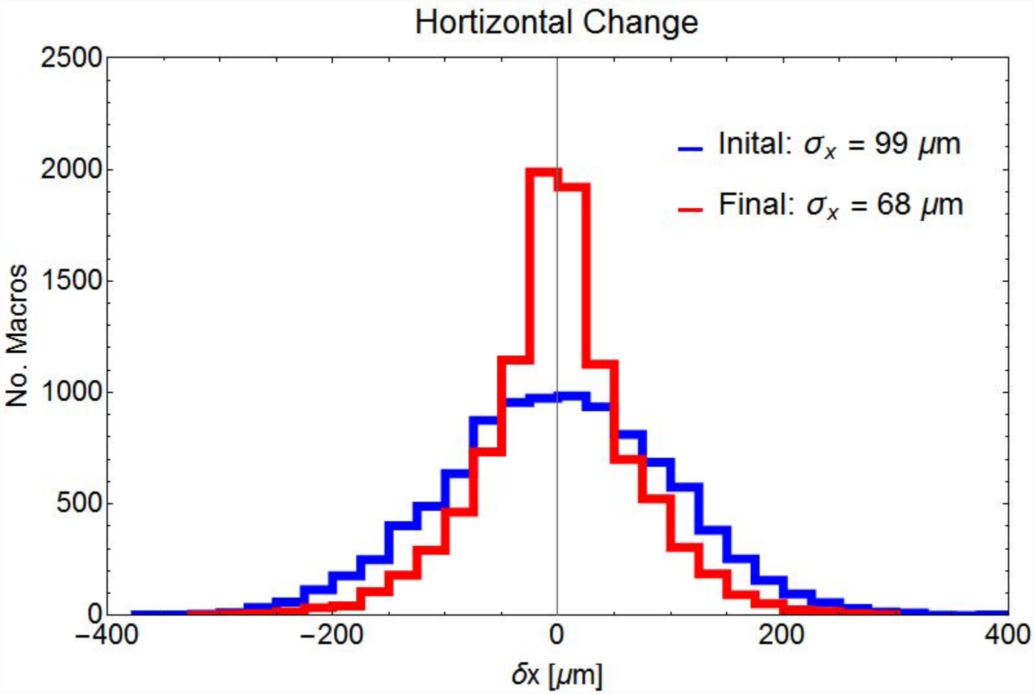
- PIC Space charge tracking code developed at LBNL J. Qiang [3,4]
- DWA element by D. Mihalcea based on 3D extension of [2]
- Use of this element validated against VSim in [5], agreement of energy loss & spread within 5%

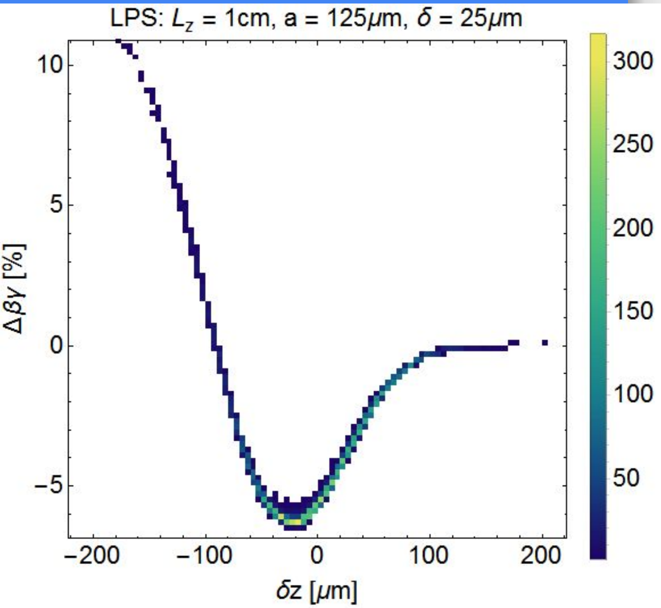
- 3D simulation, including transverse wakes.
- Fourier decomposition of the horizontal bunch profile to get coupling to higher order modes.
- Horizontal bunch profile is symmetric and cannot be offset.

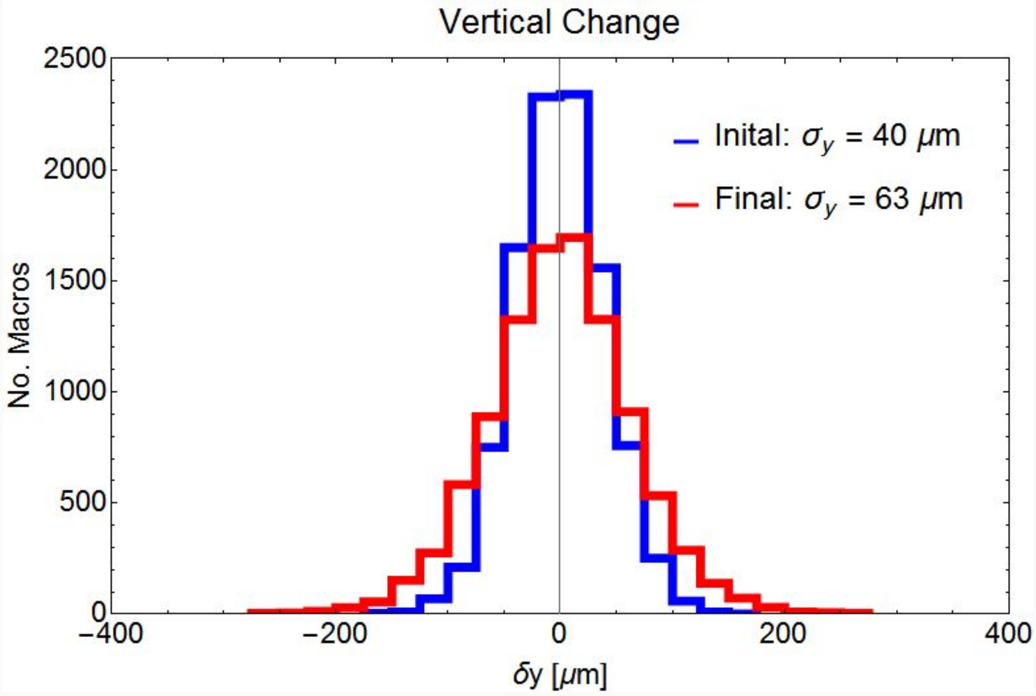
[4] http://portal.nersc.gov/project/m669/IMPACT-T/
[3] Qiang, Ji, et al. "Three-dimensional quasistatic model for high brightness beam dynamics simulation." *Physical Review Special Topics-Accelerators and Beams* 9.4 (2006): 044204.
[5] Mihalcea, D.,et al.. "Three-dimensional analysis of wakefields generated by flat electron beams in planar dielectric-loaded structures." *Physical Review Special Topics-Accelerators and Beams* 15.8 (2012): 081304.

Transverse wakes with Impact-T

- 45 MeV cold Gaussian beam with σ_z = 50 μm, Q = 250 pC, no offset
- 10 cm long structure, with a = 125 μm and δ = 25 μm
- Head-tail acceleration regime



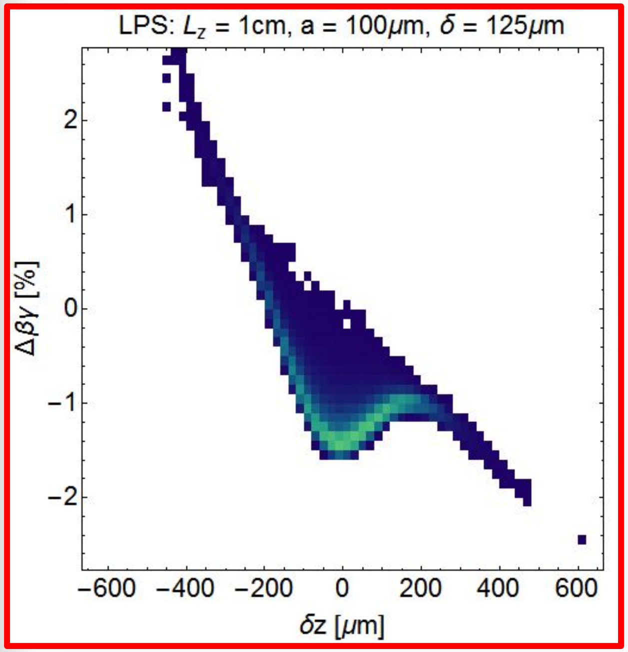


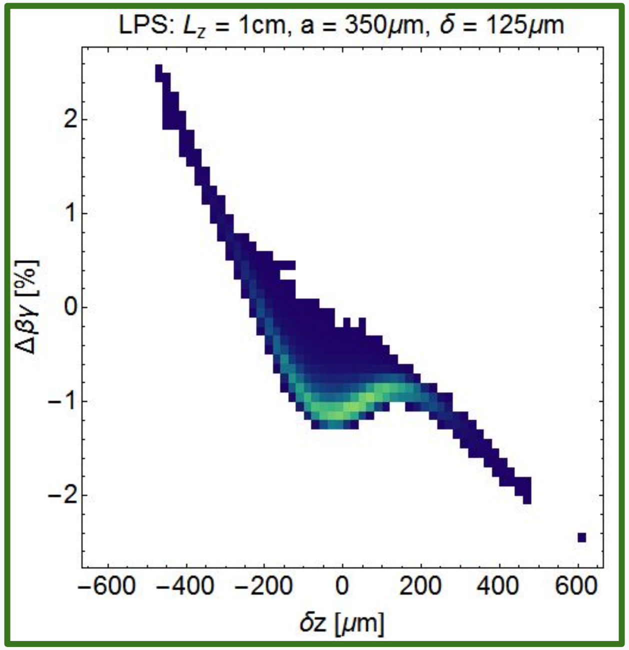


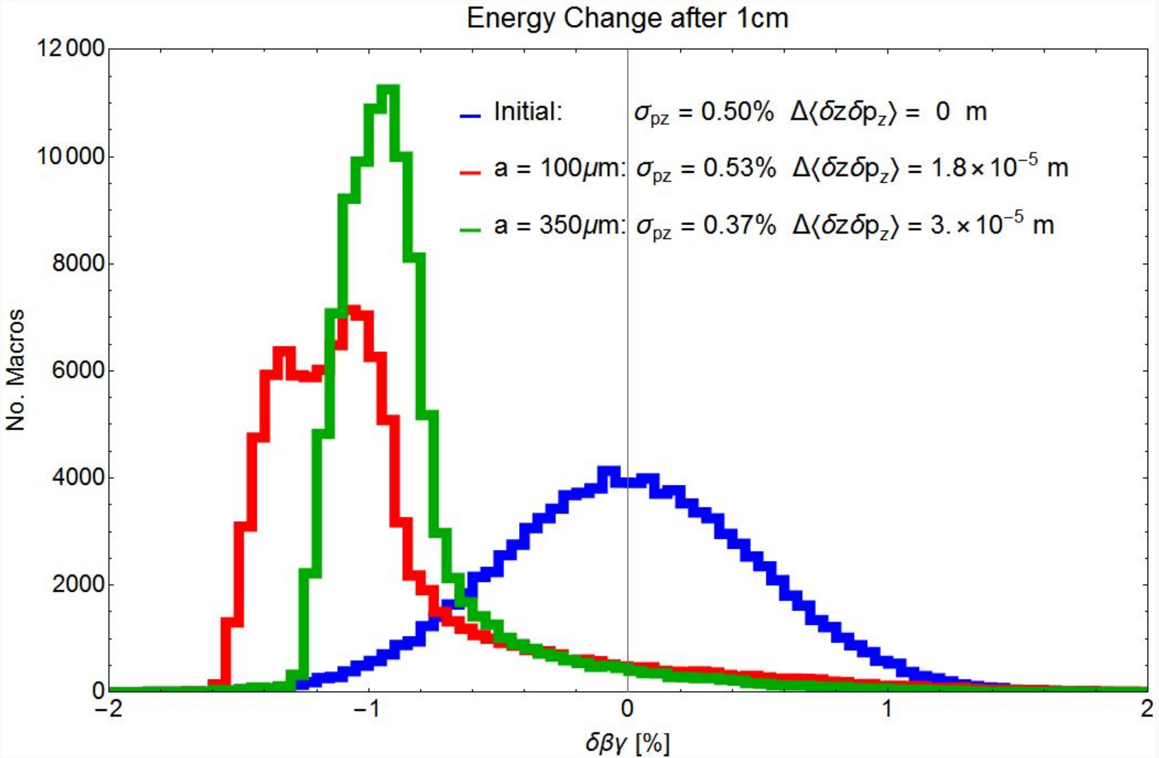
Correction for negative chirp

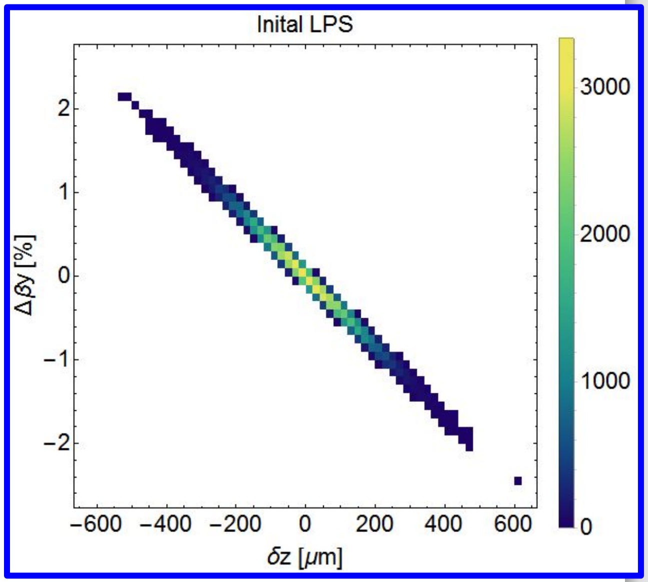
- Used for chicane compression
- Experimentally demonstrated in [6]
- Excite a mode with ½ wavelength longer than bunch; **σ_z = 120μm**
- **δ = 125 μm L_z = 1cm**

[6] Antipov, S., et al. *Physical review letters* 112.11 (2014): 114801.



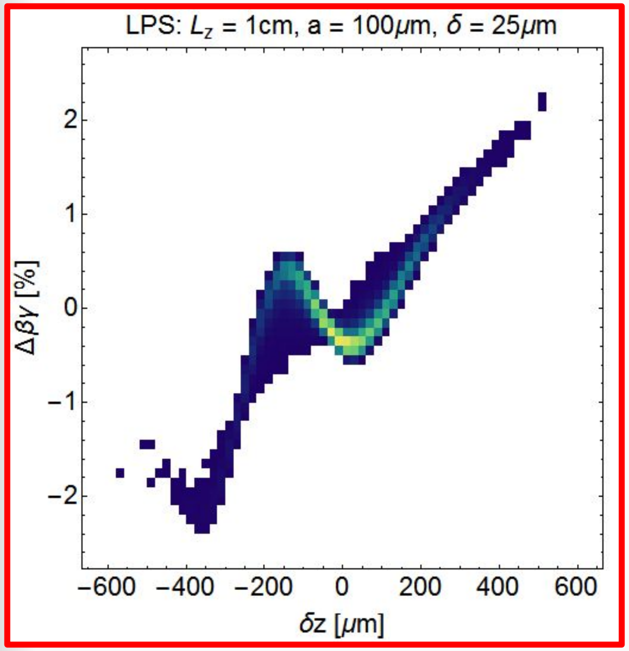


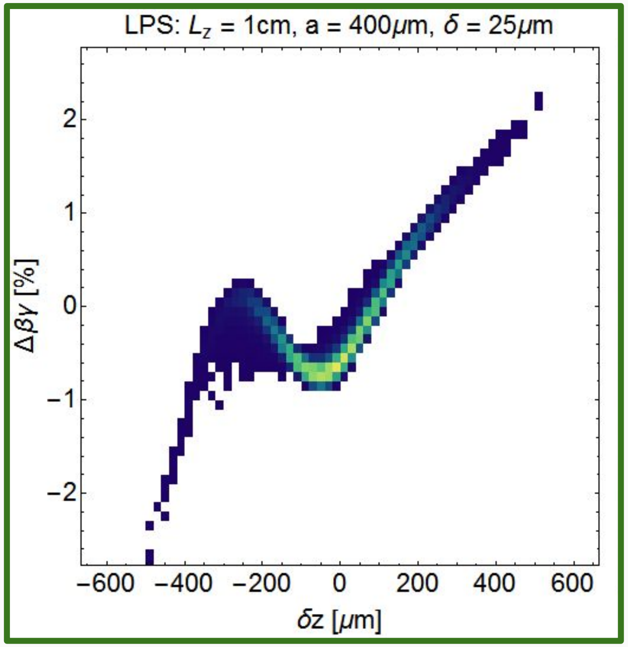


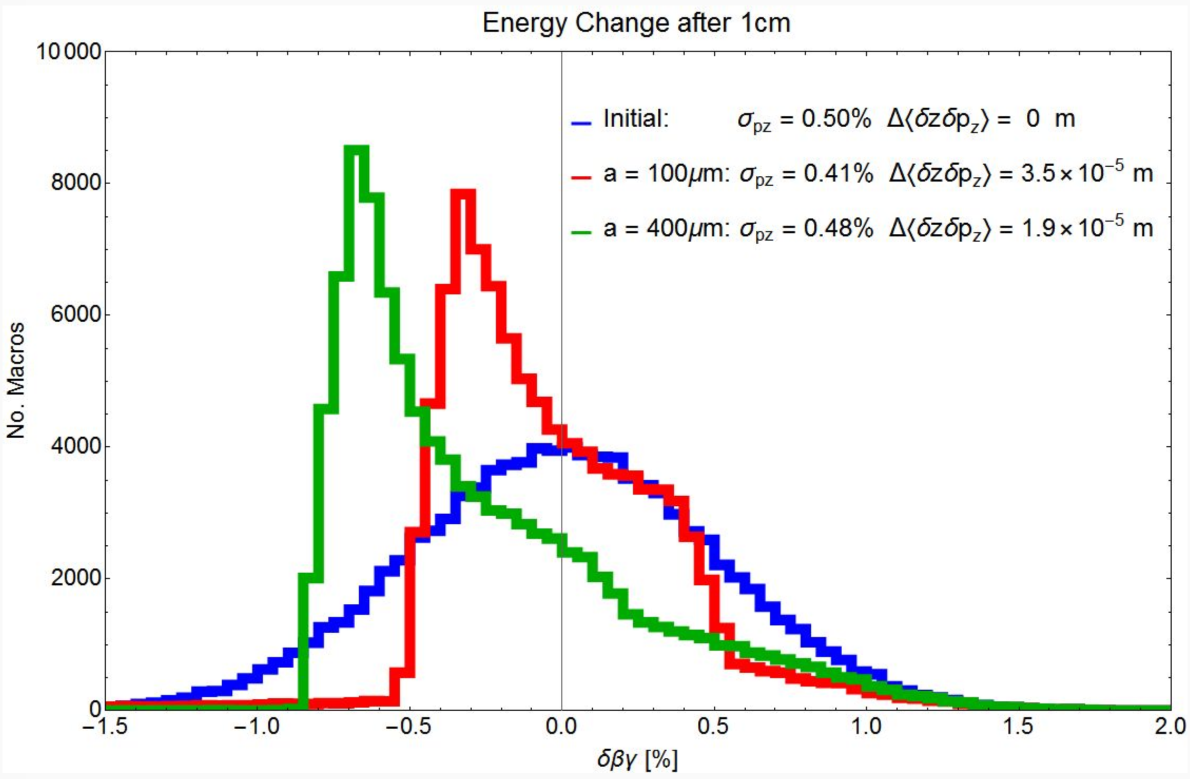


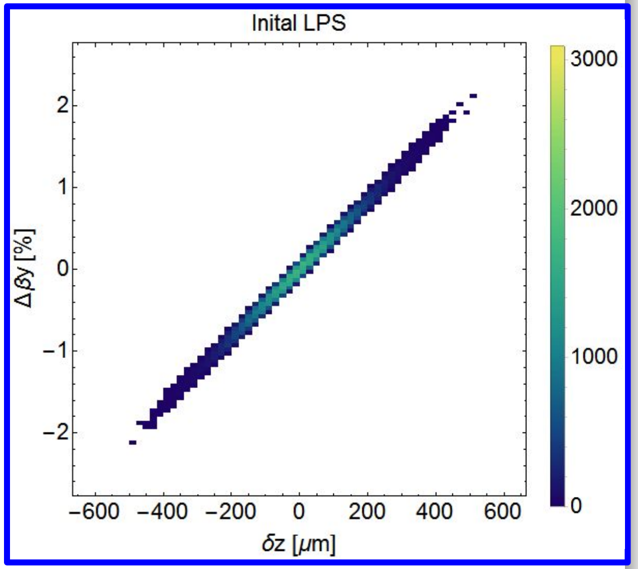
Correction for positive chirp

- Compression in doglegs
- Applicable to CLARA-FE BA1
- Excite a fundamental mode with wavelength of order bunch length
- **δ = 25 μm L_z = 1cm**









Future work

- Tunability of positive dechirper for varying energy spread
- Validate Impact-T against VSim (transverse wakes)
- Utilise a more physically reasonable input bunch for CLARA-FE
- Detailed analysis of transverse wakes and stability

- Development of Martin-Puplet Interferometer for characterisation of wake spectrum
- Looking towards starting experiment in 2017

Summary

- Highly tunable structure will not be optimised for high gradient acceleration
- Simulations show DWA can be used for variably dechirping both positive chirp
- Preparations being made for experimental work in 2017