Positron Driven High-Field Terahertz Waves via Dielectric Wakefield Interaction

Nathan Majernik*,[1], Gerard Andonian [1], Oliver Williams [1], Brendan O'Shea [2], Phuc Hoang [1], Christine Clarke [2], Mark Hogan [2], Vitaly Yakimenko [2], James Rosenzweig [1]

[1] UCLA, Los Angeles, CA, USA

[2] SLAC, Menlo Park, CA, USA

*Corresponding author: NMajernik@g.ucla.edu

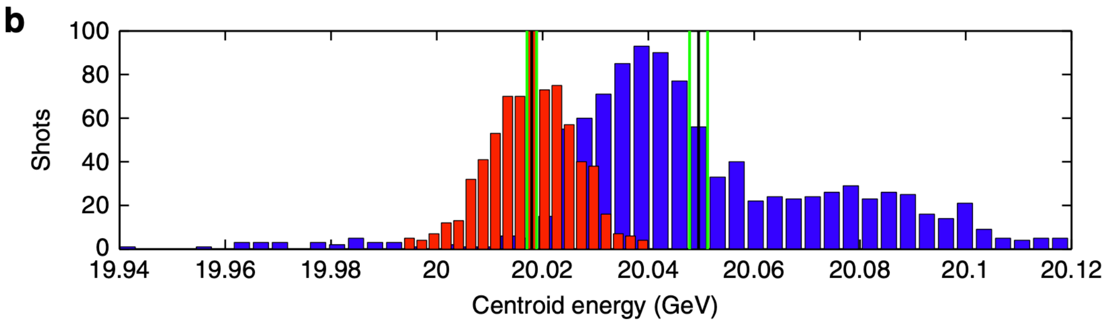
UCLA

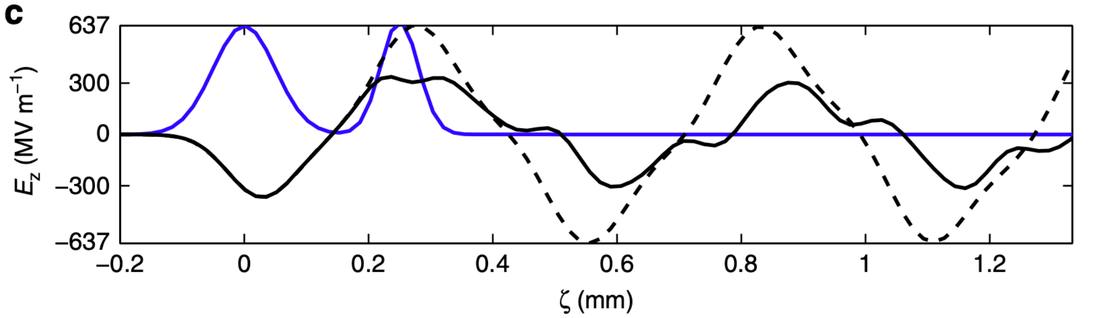
SLAC NATIONAL ACCELERATOR LABORATORY

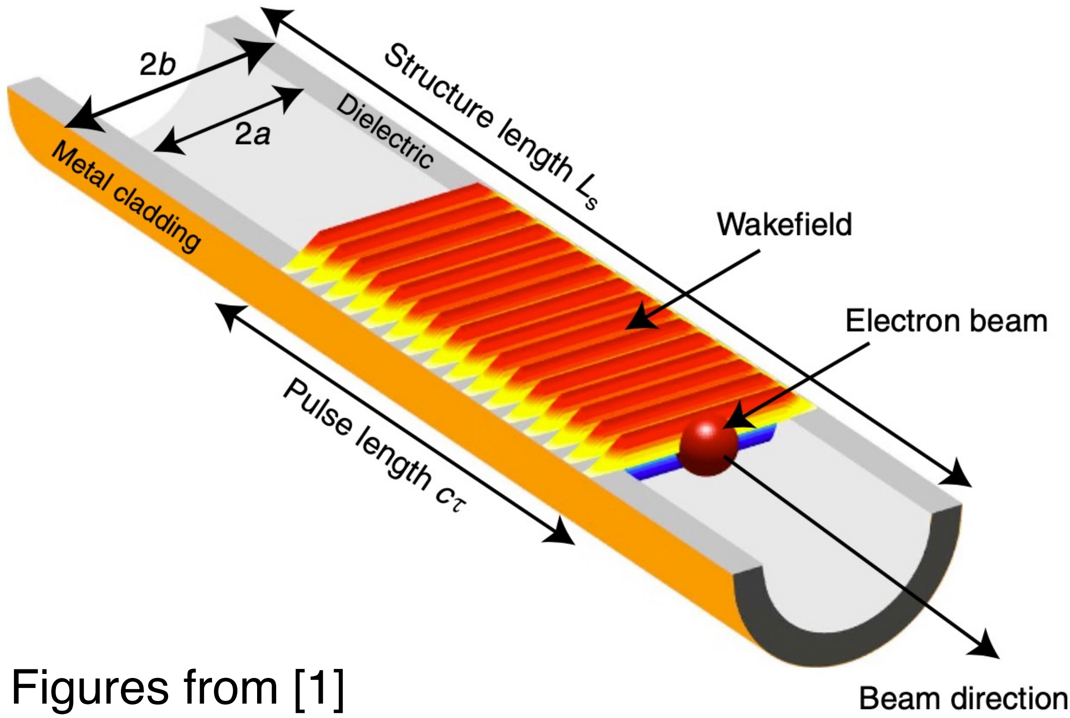
U.S. DEPARTMENT OF ENERGY

Dielectric wakefield acceleration

- Beam driven wakefields in a dielectric structure
  - Many applications including accelerating, chirping, deflecting, focusing, THz generation, and more
- Can access GV/m-scale accelerating gradients
- Discussed as an “afterburner” option for a linear collider or light source
- Easier implementation than some other advanced accelerators



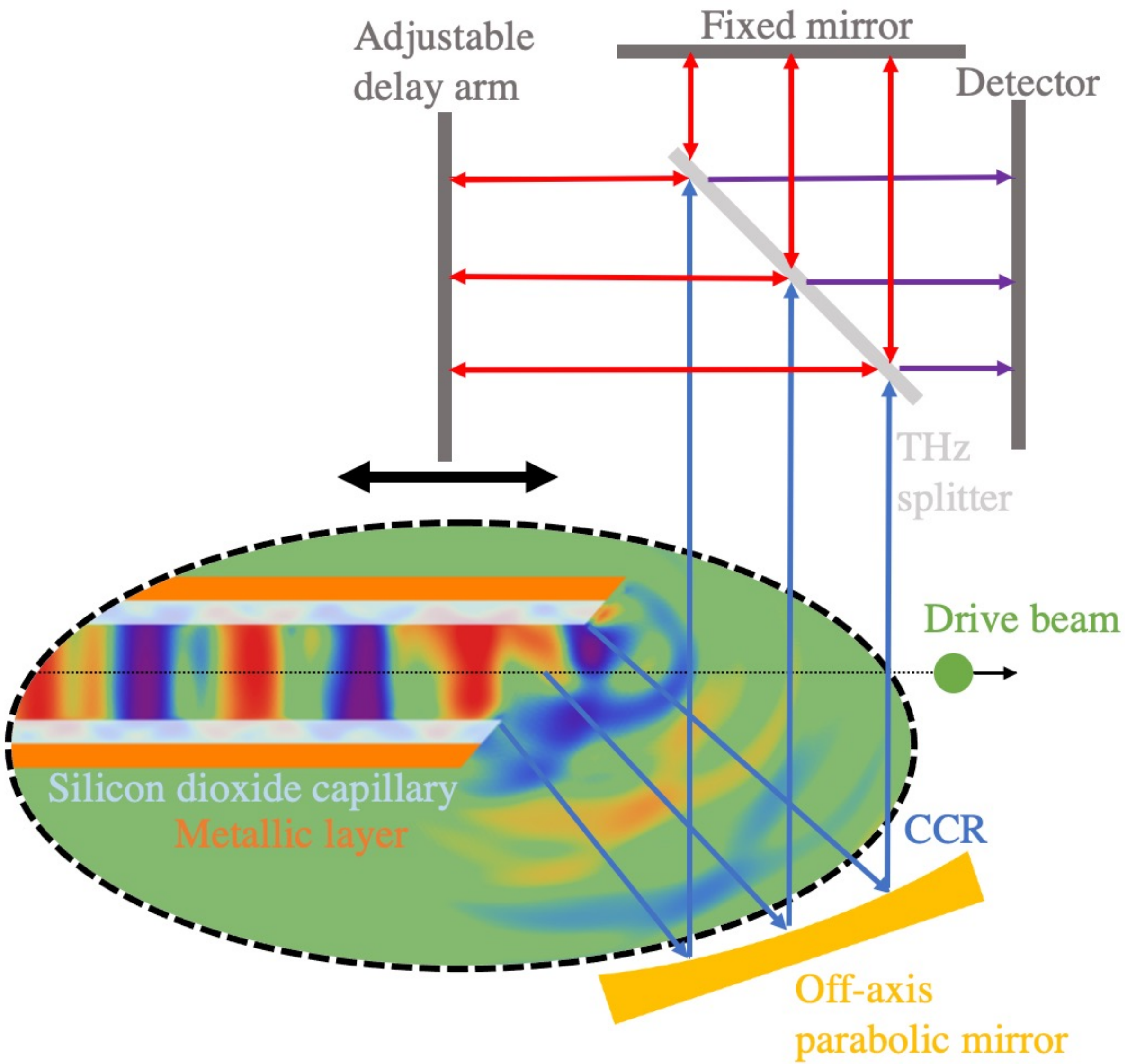




Figures from [1]

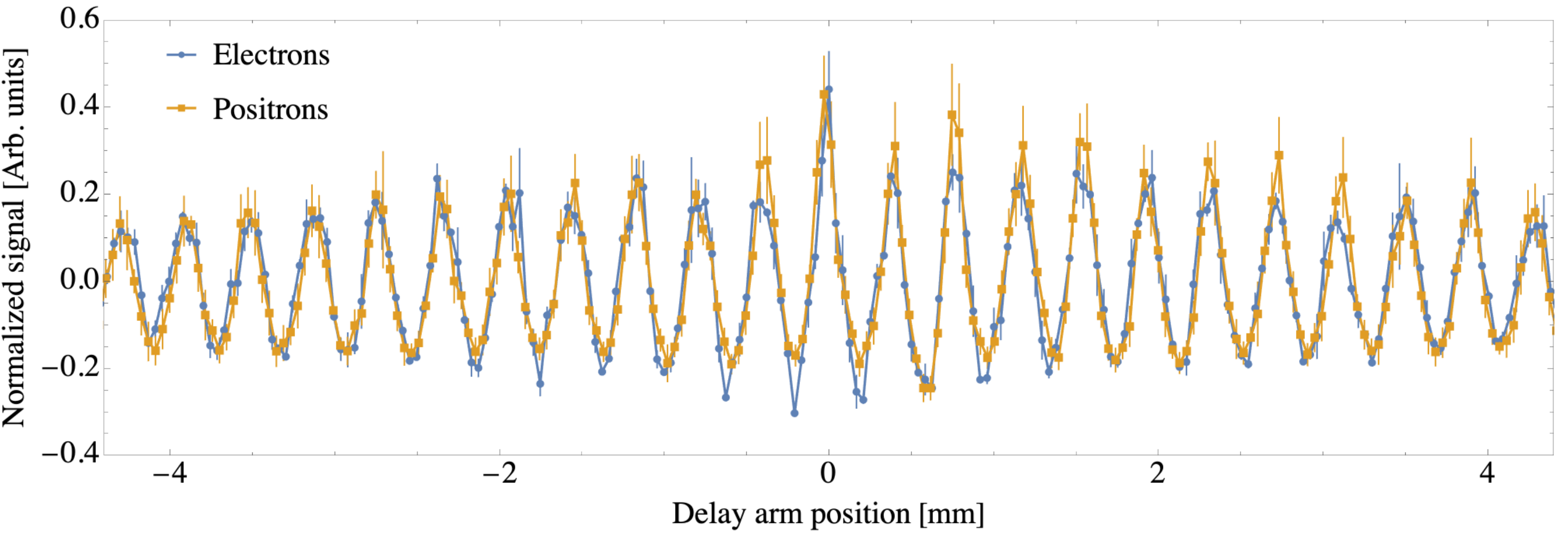
Positron driven DWA experiment

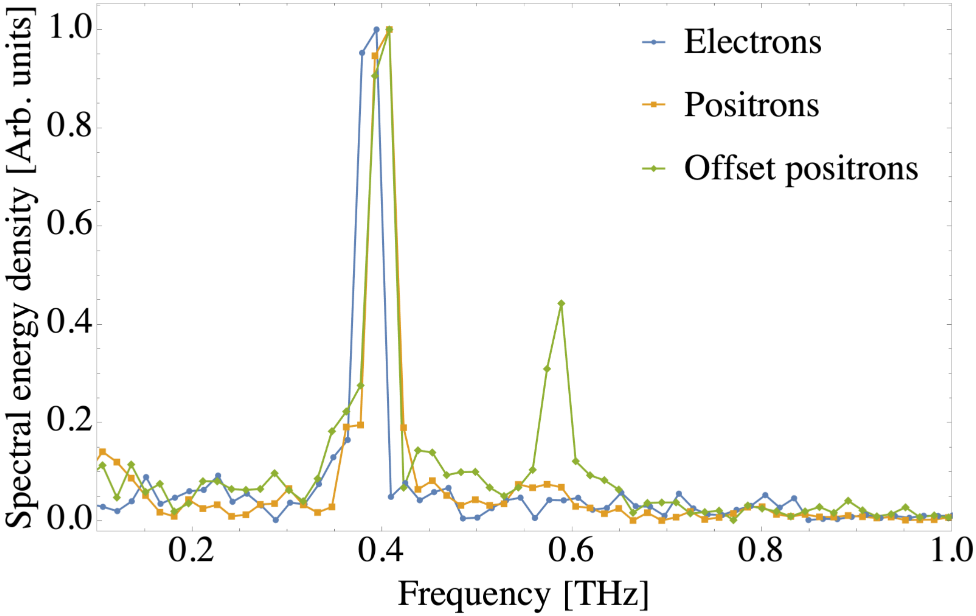
- DWA process is symmetric with respect to charge sign (to *first order*)
  - PWFA fundamentally is not
  - What about higher order effects?
- Comparing electrons to positrons where the only experimental variable is charge sign
  - **First ever positron DWA**
  - Collider relevant beam specs
  - 20 GeV, 0.7 x 10^{10} particles, $\sigma_x = \sigma_y = \sigma_z = 40$ μm
  - Silicon dioxide capillary: IR/OR = 200/300 μm, 3 cm length
- Coherent Cherenkov radiation (CCR) used as diagnostic
  - Measured using THz autocorrelator



Autocorrelator results

- Autocorrelator delay changed in 42 µm steps
- Fundamental mode = 0.4 THz
- Peak E_z = 500 MV/m
  - Below electron high-field damping threshold ≈ 850 MV/m [2]
- Electron and positron traces appear equivalent
  - Do not exhibit signatures of damping

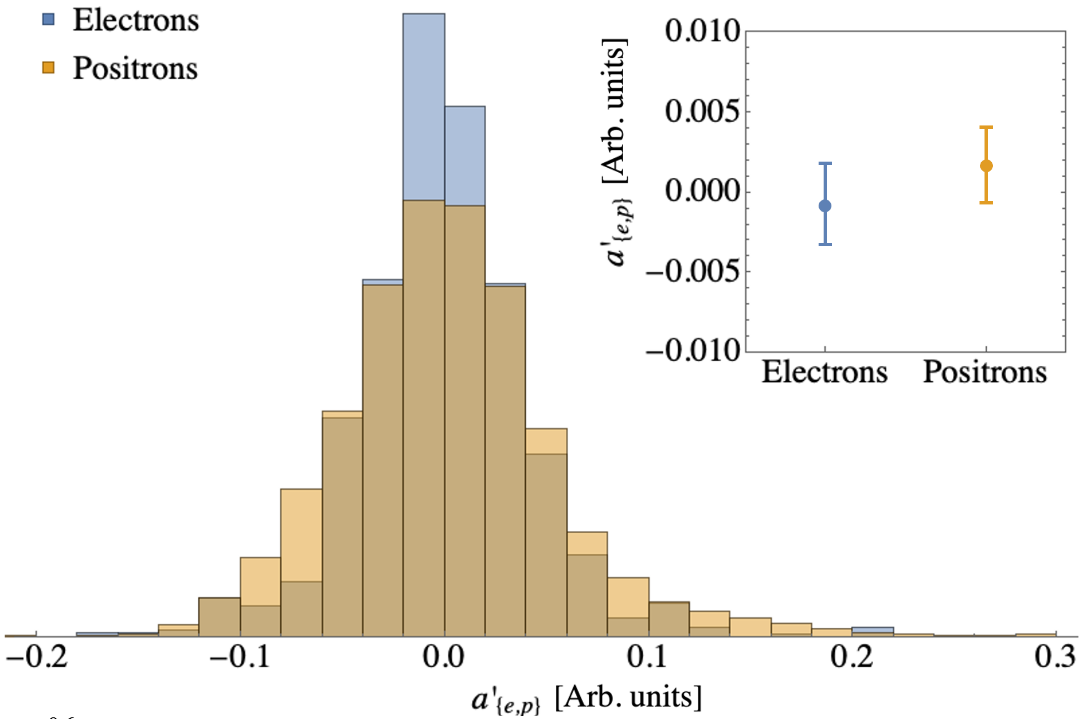


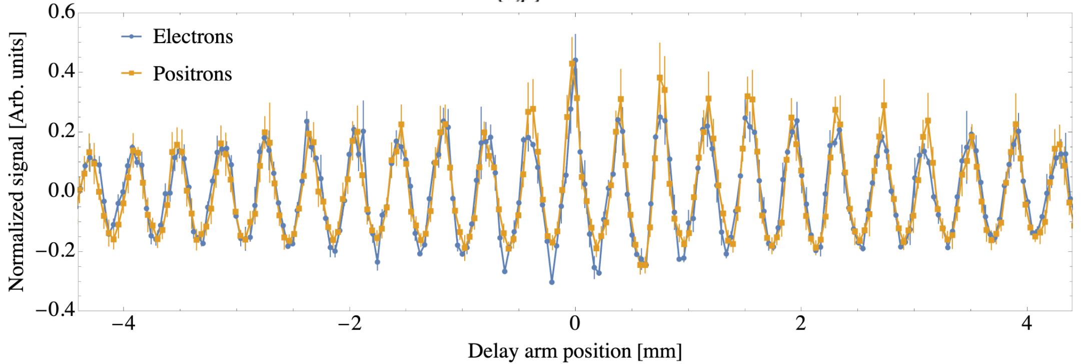


Statistical equivalence

- Need to do some gymnastics to compare
  - For each species, calculate linear interpolations
  - Align and calculate mean trend line
  - Subtract from each point to create updated populations
- Assert smallest effect size of interest (SESOI) and perform two-one sided test (TOST)
- Reject TOST null hypothesis (difference > SESOI) at 95% confidence level (p = 0.000)
- Conclude electron and positron responses are statistically equivalent

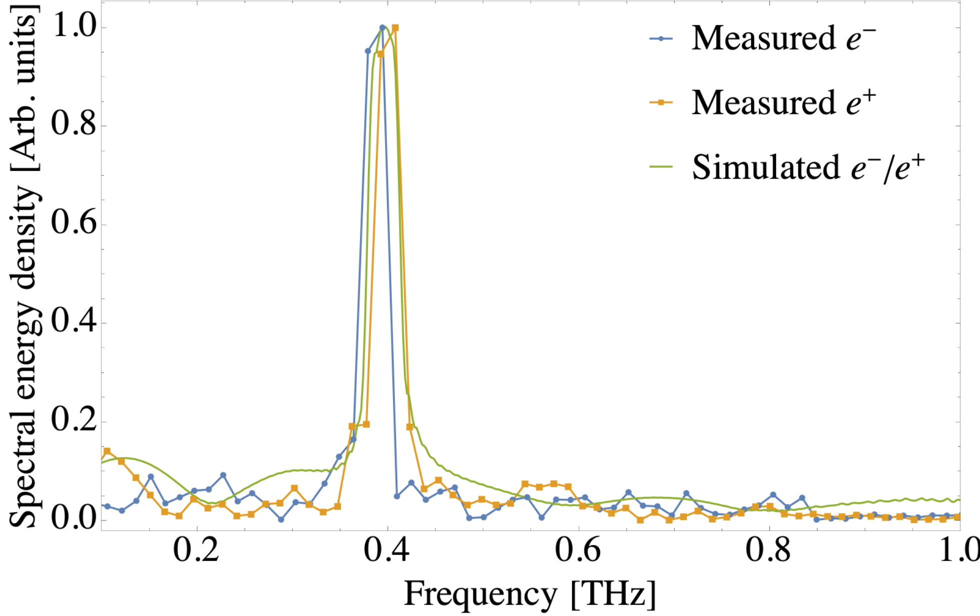
$$a'_{\{e,p\},k}(z_i) = a_{\{e,p\},k}(z_i) - m_t(z_i)$$

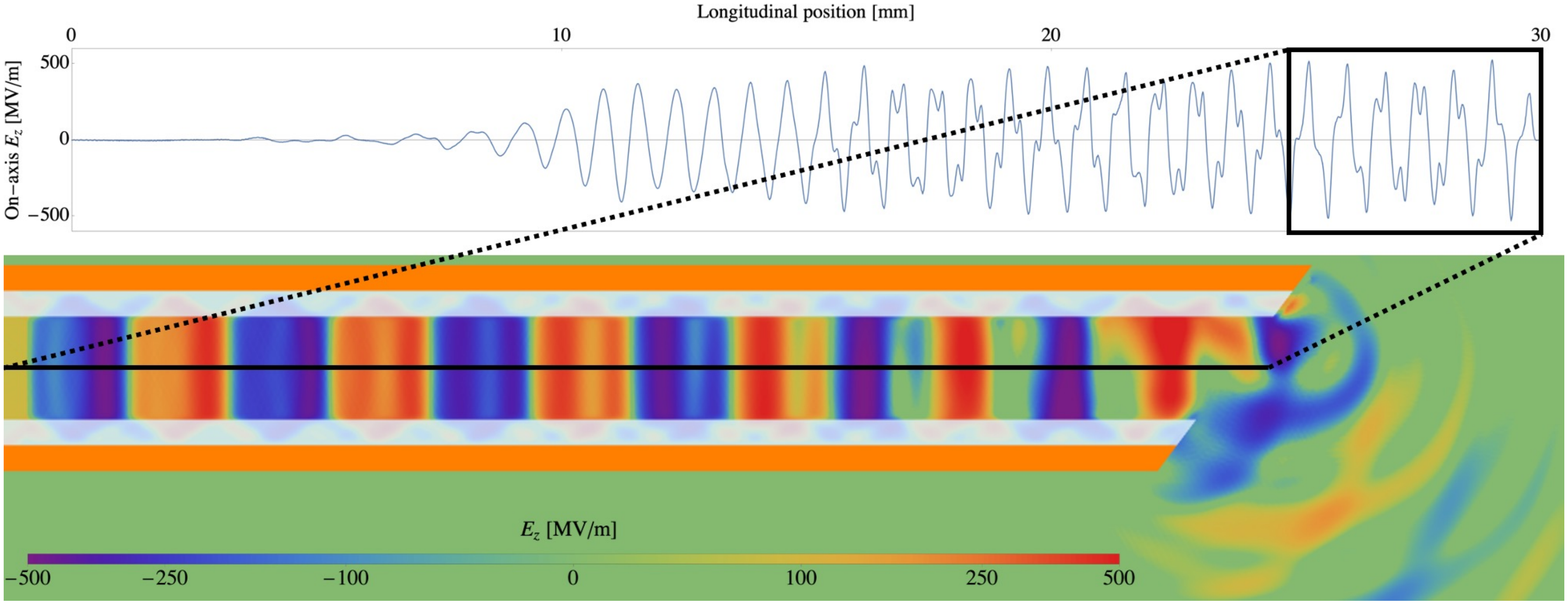




Simulations

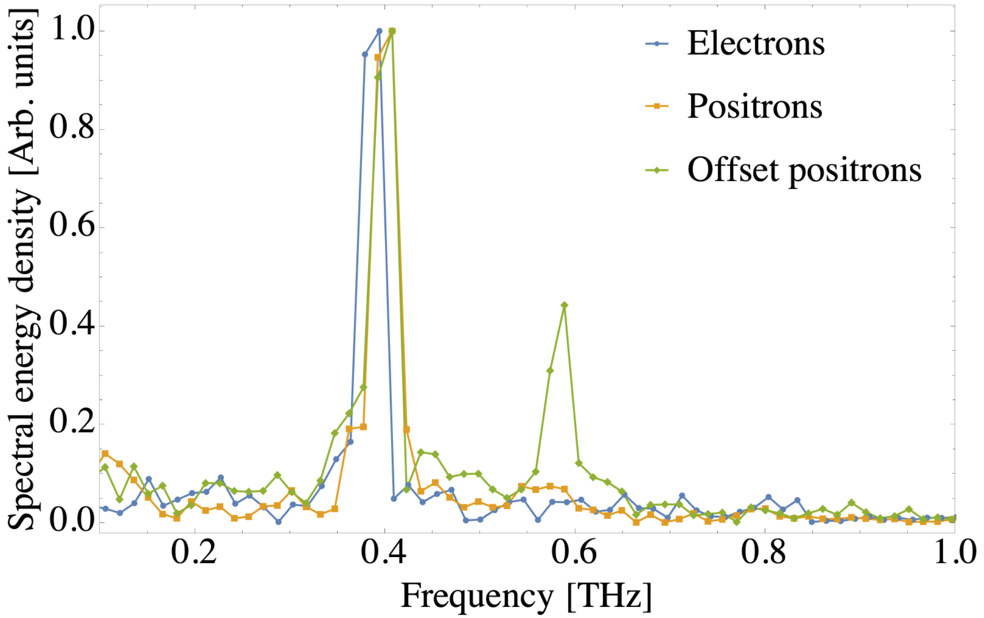
- Simulated scenario in PIC
  - Unknown higher order effect not included; by construction would be sign symmetric
- CCR spectrum agrees with experiment

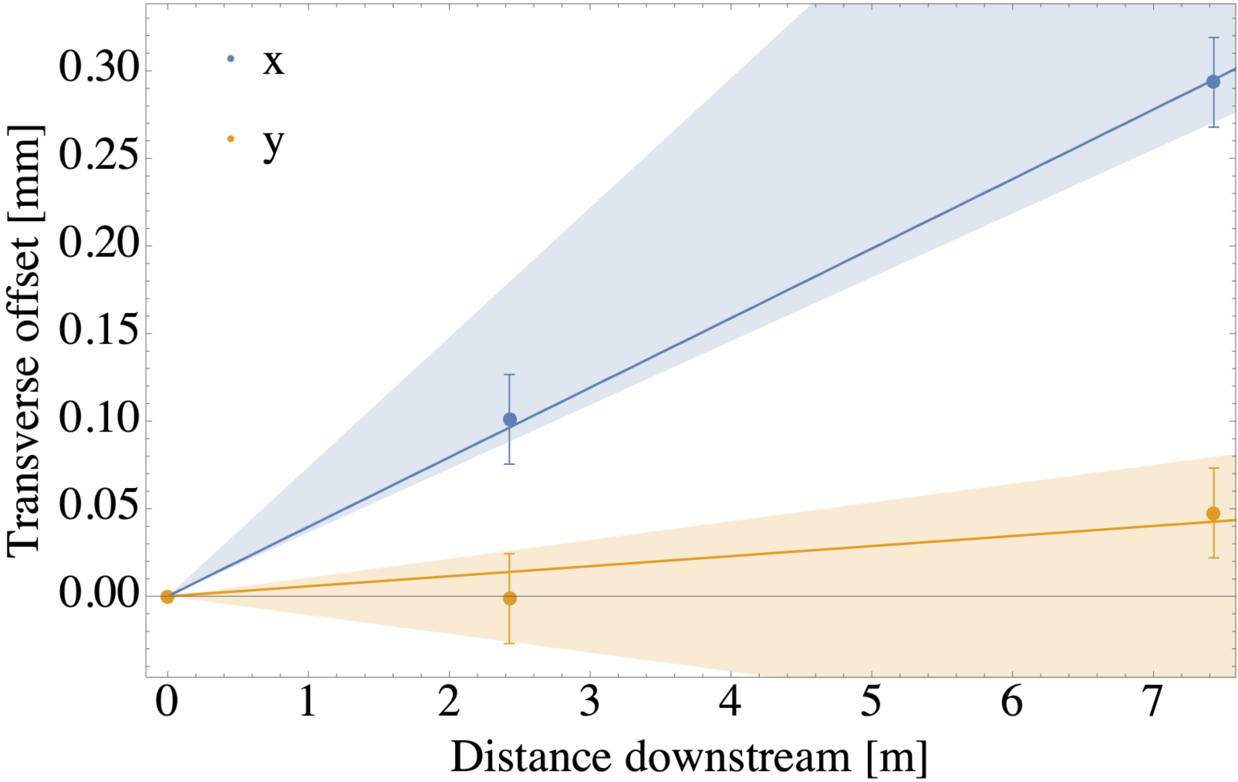




Offset beams

- Positron bunches run 60 µm off-axis in x
- Excites HEM_{12} mode (0.58 THz)
  - Applies transverse kick
- Beam position measured by two BPMs
  - Compared to simulation; shown as error bands due to uncertainty in structure position





Conclusions

- Dielectric wakefield acceleration can access GV/m gradients
- Symmetric with respect to charge sign to first order
  - Valid to at least 500 MV/m
  - Appealing as an afterburner for e^+e^- linear collider
- Experimental results of first ever positron DWA with witness-bunch-relevant beam parameters show that higher order effects are not induced
  - Statistical equivalence with electrons demonstrated
- Transverse kicks from off-axis positron propagation measured and found to agree with simulation
- Important progress towards dielectric wakefield acceleration of positrons

UCLA SLAC NATIONAL ACCELERATOR LABORATORY U.S. DEPARTMENT OF ENERGY

References and acknowledgements

- [1] - BD O'Shea, G Andonian, SK Barber, KL Fitzmorris, S Hakimi, J Harrison, PD Hoang, MJ Hogan, B Naranjo, OB Williams, et al. Observation of acceleration and deceleration in gigaelectron-volt-per-metre gradient dielectric wakefield accelerators. *Nature communications*, 7(1):1–7,2016.
- [2] - O'Shea, Brendan D., et al. "Conductivity induced by high-field terahertz waves in dielectric material." *Physical review letters* 123.13 (2019): 134801.

- This work was supported by the Department of Energy High Energy Physics Grant DE-SC0009914.
- Published as: Majernik, N., et al. "Positron driven high-field terahertz waves via dielectric wakefield interaction." *Physical Review Research* 4.2 (2022): 023065.