Dielectric wakefield accelerator experiments in modal confinement and pulse shaping

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La Biodola, Isola d'Elba

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Outline

DWA experimental results from BNL ATF in THz regime

1. Bunch profile shaping with wakefields
2. Single mode confinement using DWA with Bragg boundaries

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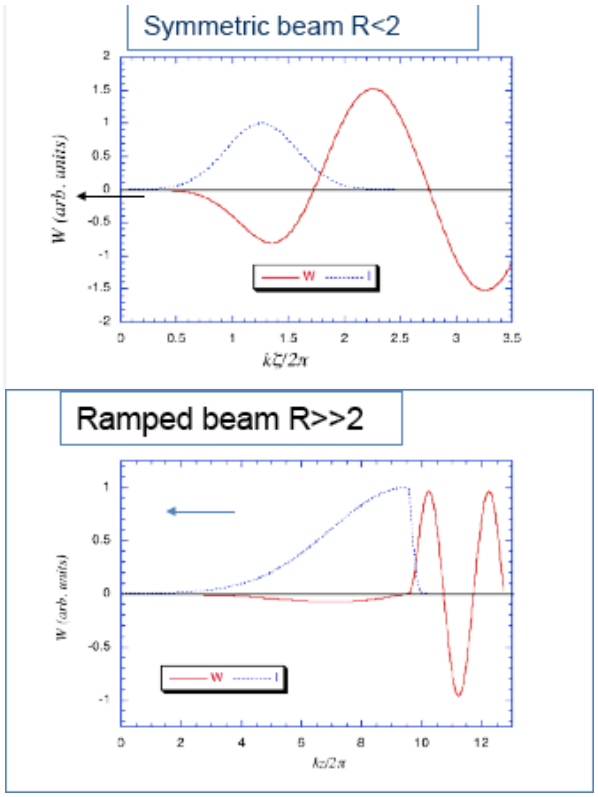
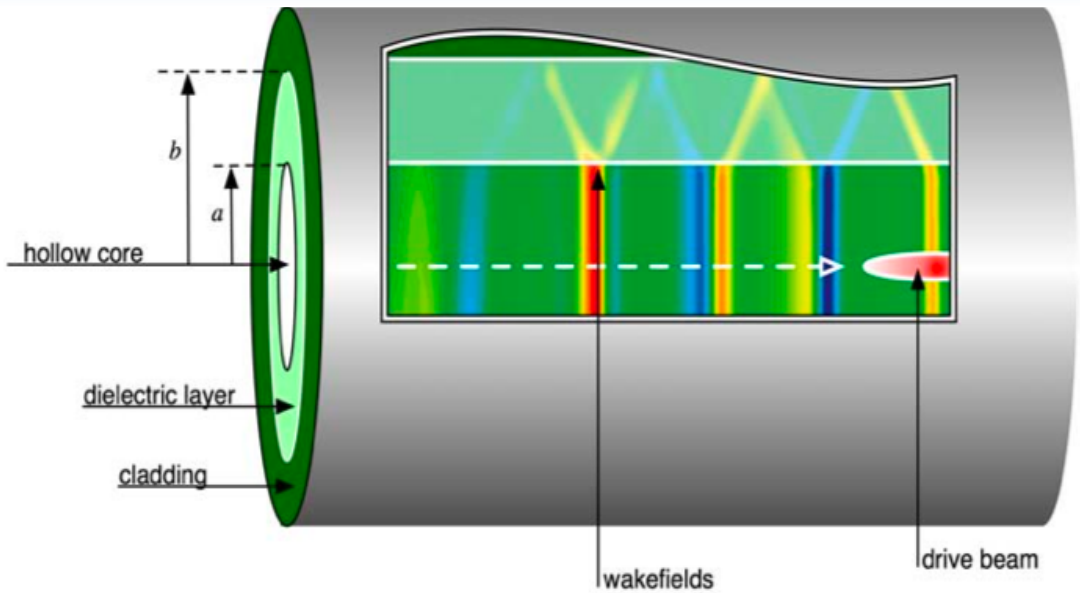
Motivation: Ramped bunches

- Transformer ratio enhancement
  - R = 2 for symmetric bunches
  - R > 2 for shaped bunches (triangle, etc)*
- Current techniques
  - EEX, masking dispersive section, laser shaping on cathode
- Alternative concept
  - Bunch Shaping with wakefields from dielectric structure



*K. Bane SLAC-PUB3662 (1985) ,
B. Jiang PRSTAB 15 011301 (2012)

Dielectric lined conductor



- Peak decelerating field

$$eE_{z,dec} \approx \frac{-4N_b r_e m_e c^2}{a\left[\sqrt{\frac{8\pi}{\varepsilon-1}}\varepsilon\sigma_z + a\right]}$$

- Fundamental mode

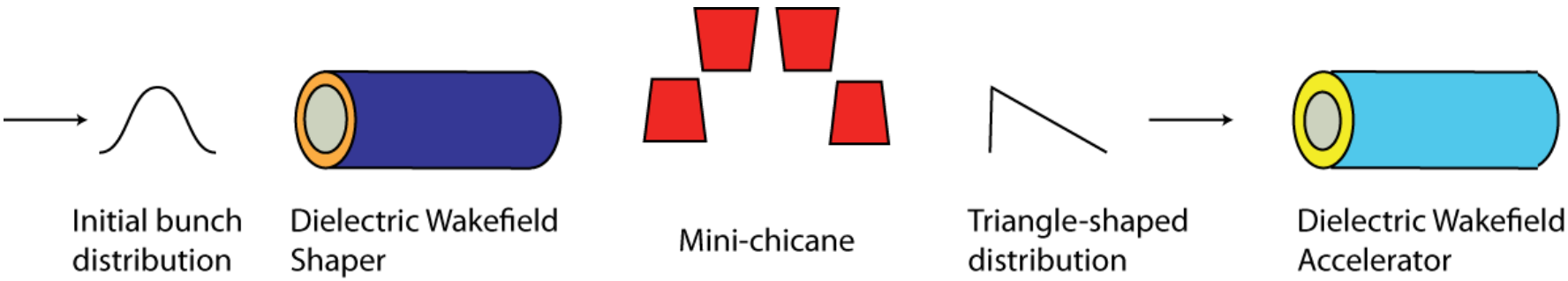
$$f_{01} = \frac{c}{2\pi}\sqrt{\frac{2\,\epsilon}{(\epsilon-1)a\,(b-a)}}$$

- Advances in nano-fabrication and high-brightness beam prep allow for THz (sub-mm) scale structure
- Recent experimental results
  - Beam acceleration at BNL ATF, FACET
    - (see B. O'Shea talk)
  - Narrowband, high power THz source
  - Phase space modulation (dechirping, microbunching)*

- Transformer ratio (unshaped beam)

$$R = \frac{E_{z,acc}}{E_{z,dec}} \leq 2$$

Ramped Bunch Shaping Concept



- Wakefield (E_z) tuned to "ramp" energy modulation
  - Shaping criteria: $\lambda/\sigma_z > 2$
- Chicane (R_{56}) converts to density modulation
- Use shaped bunch in DWA or PWFA
- Design knobs: ID, OD, material, geometry (e.g. planar w/ variable gap), L_d, R_{56}

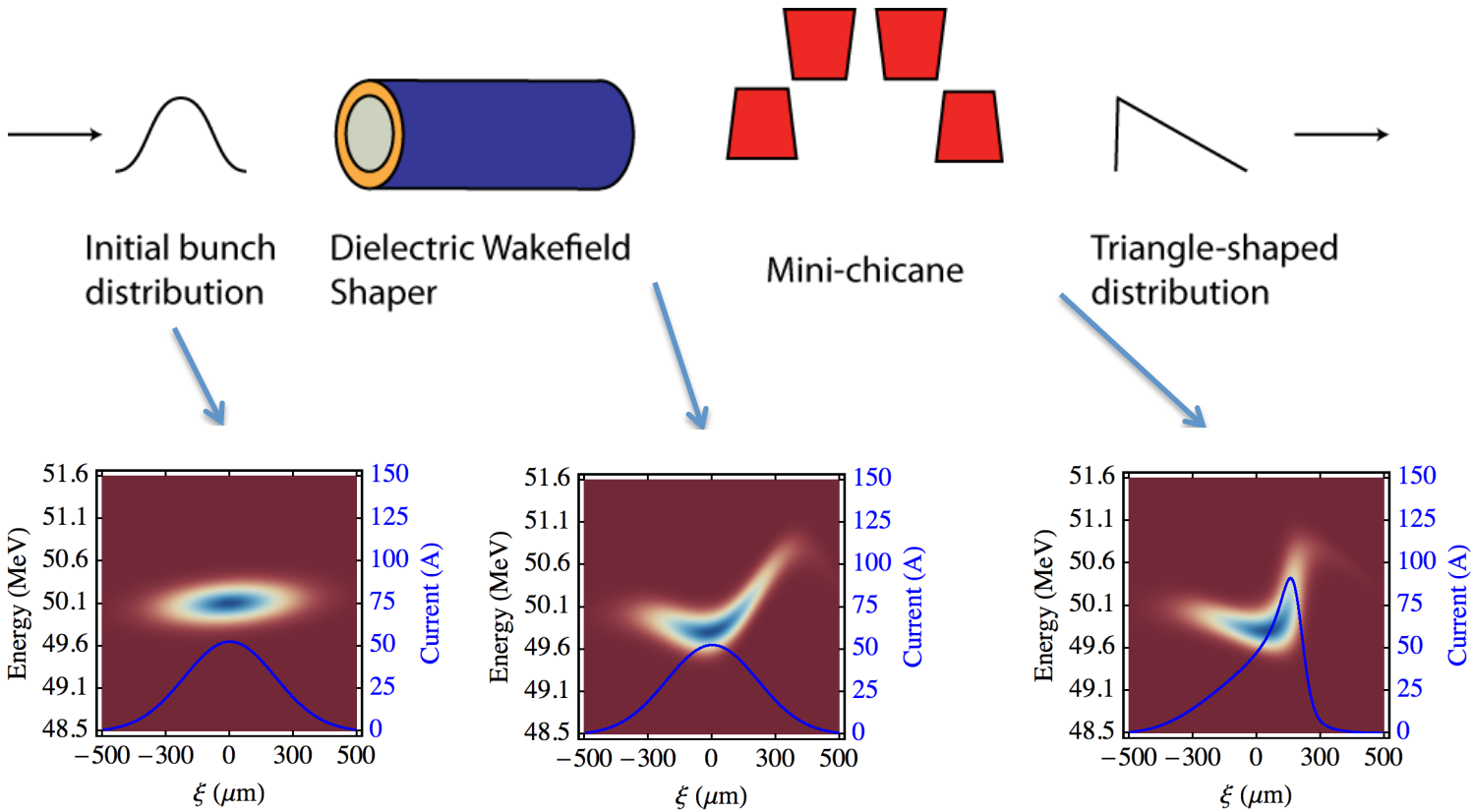
$$W(z) = -\int_0^\infty \rho(z-z')w(z')dz'$$

$$\delta(z) = \frac{q_e(Nq_e)W(z)L_d}{E_0}$$

$$z = z_0 + R_{56}\delta$$

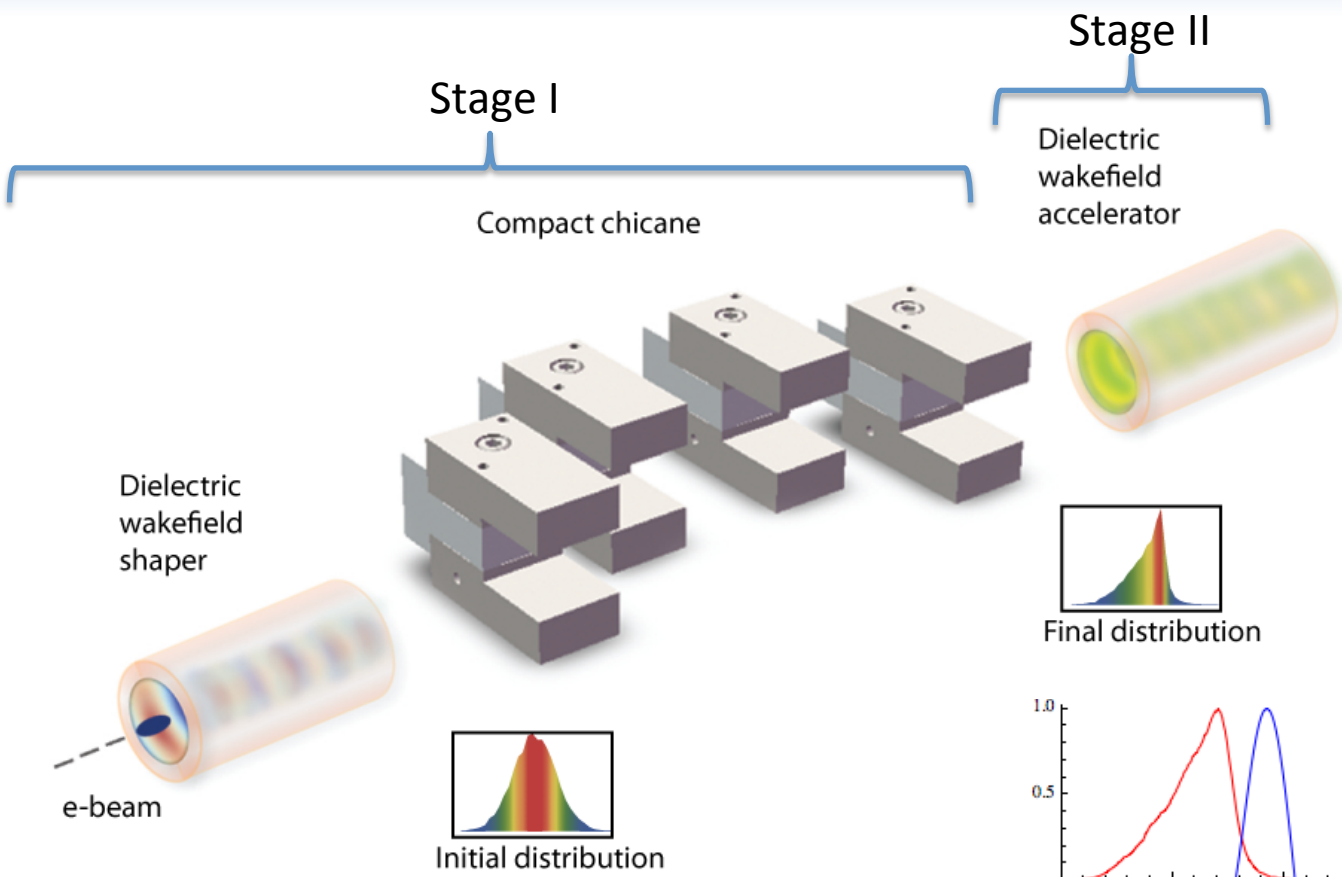
- Some Features:
  - Passive device
  - Relatively inexpensive
  - Small footprint
  - Can be close to IP
  - No loss of charge

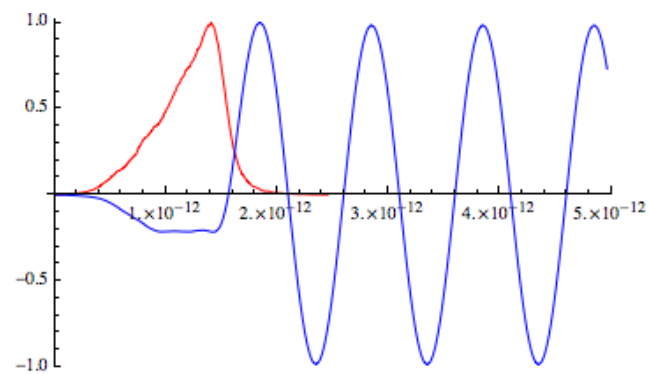
Ramped bunch shaping from self-wakefields: Example BNL ATF parameters



- BNL ATF e-beam: γ = 100, σ_z ~ 200μm, Q=80pC, ε_n = 1mm-mrad
- Structure: a/b = 200/300μm, ε = 3.8, L=5cm, f_{01}=0.39THz (λ=765μm)
- Chicane R_{56}=9.2mm
- Analytic calculations, phase space verified with OOPIC/Elegant

Experiment at BNL ATF

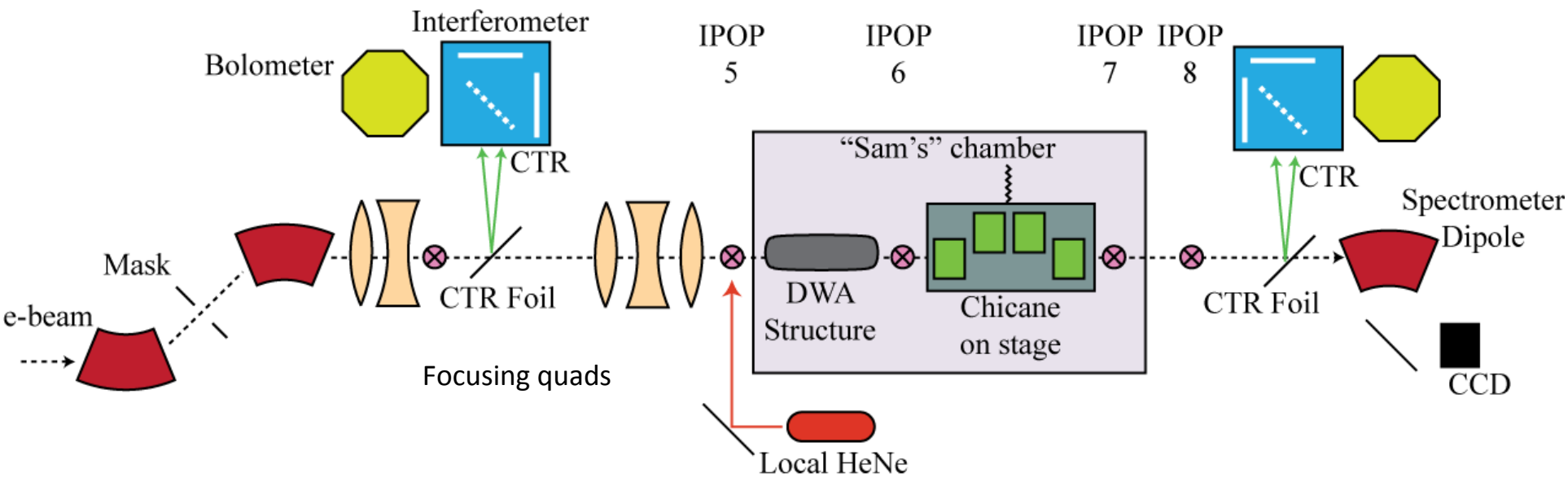




Example of wakefield of shaped beam for BNL ATF parameters

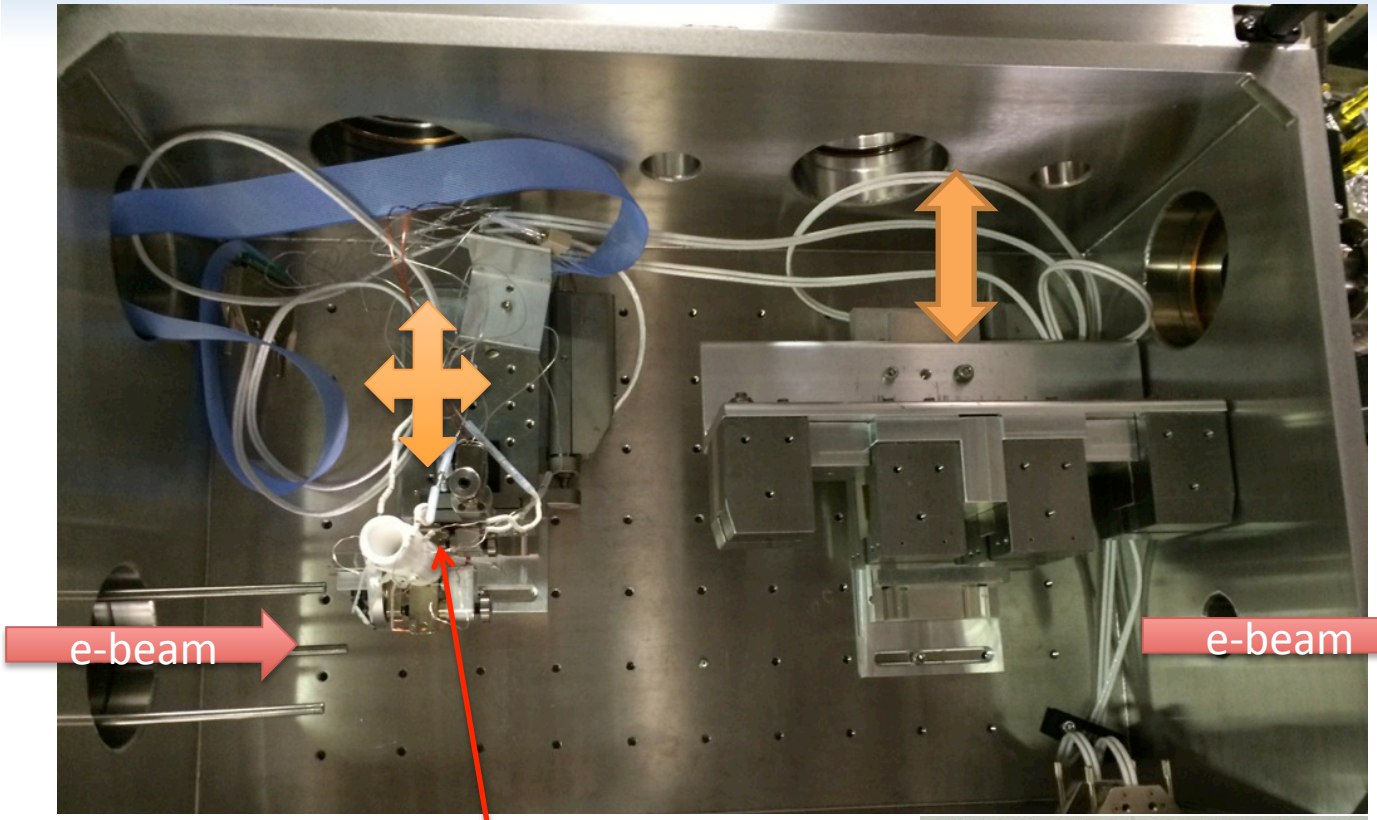
Experiment layout

BNL Accelerator Test Facility - Beamline 2



- Final focus matching optics
- Local alignment with HeNe to e-beam trajectory
- CTR interferometer Bunch length diagnostic as in *G. Andonian PRL 108, 244801 (2012),et al.*
- PM dipole chicane as in *S. Antipov PRL 111, 134802 (2013)*

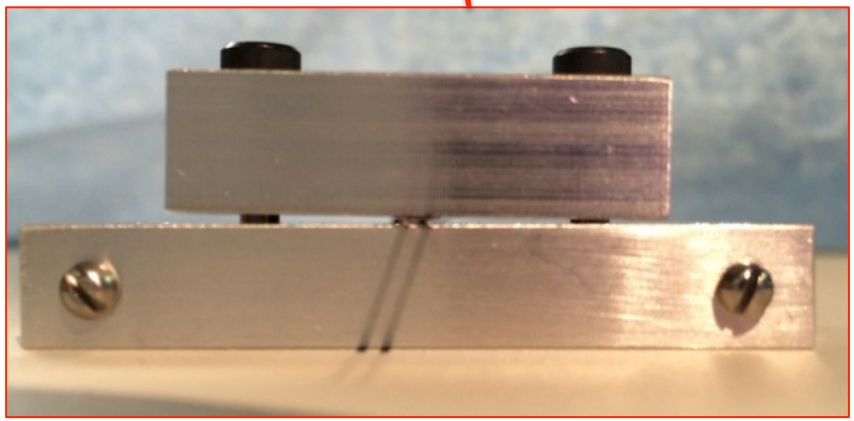
Photos of DWS in chamber

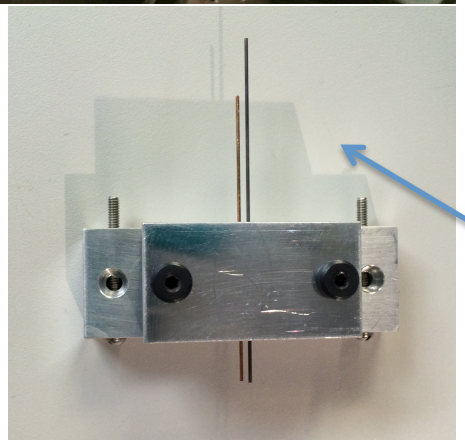


PM chicane on retractable stage

DWS on 5 axis mover

CTR foil + interferometer

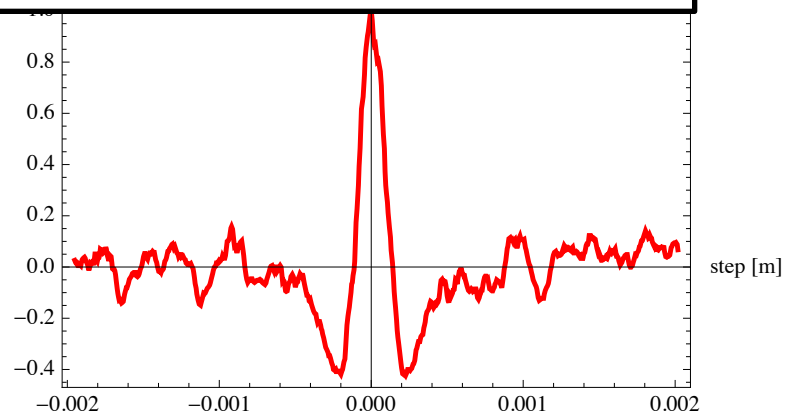




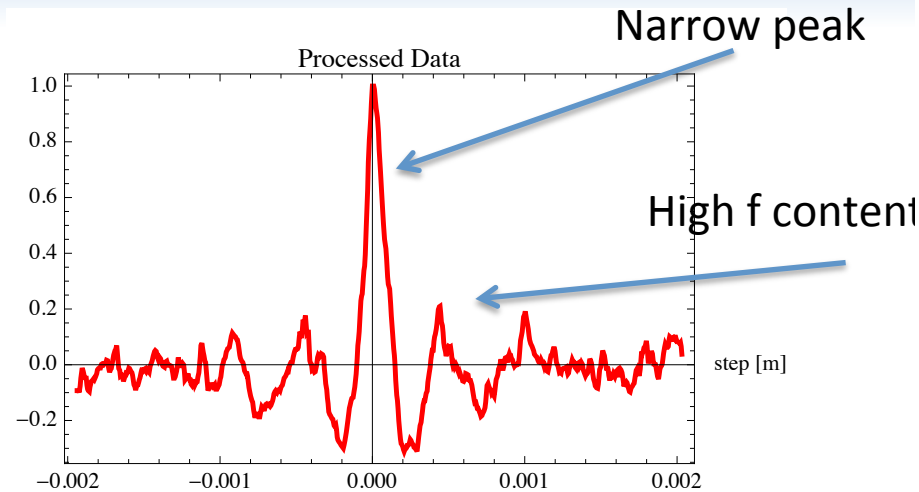
5cm, 6cm long Dielectric structures

CTR autocorrelation traces

THz Michelson interferometer, CTR analysis



No Dielectric "shaper"

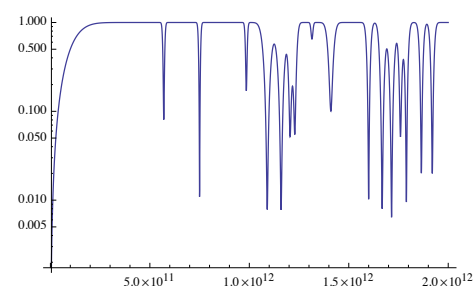


Through Dielectric "shaper"

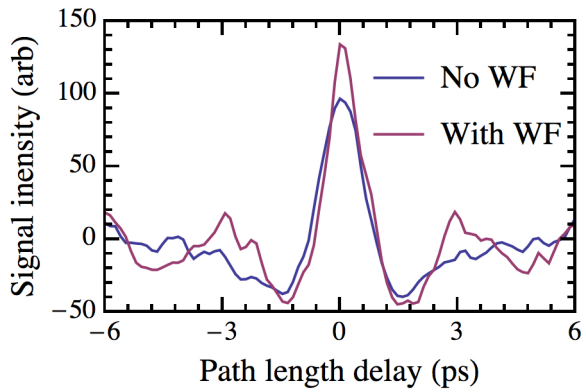
Telling features with shaper in vs shaper out:

- 1) Narrower central peak → bunch compression
- 2) Higher frequency content → asymmetric ramp in distribution

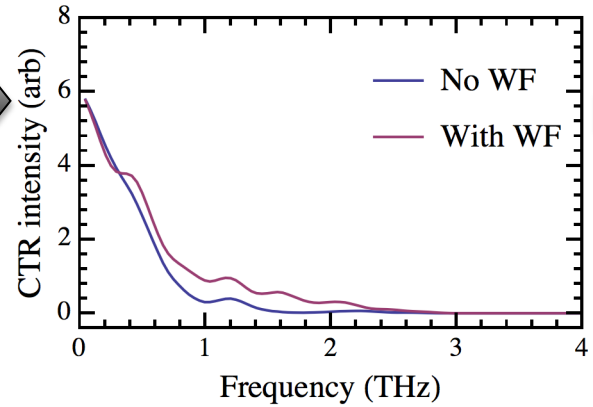
Use full Kramers-Kronig reconstruction with known cutoff frequency in transport and water absorption lines…



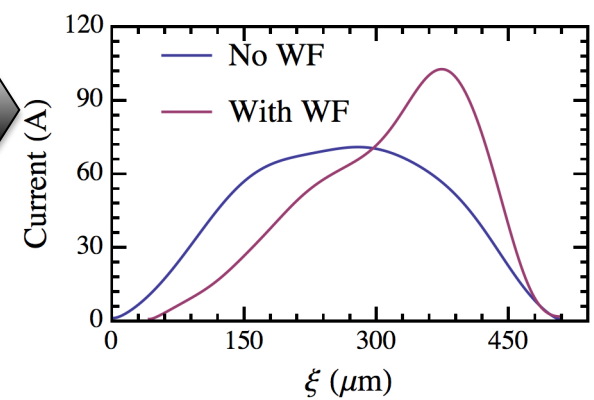
CTR interferometry analysis



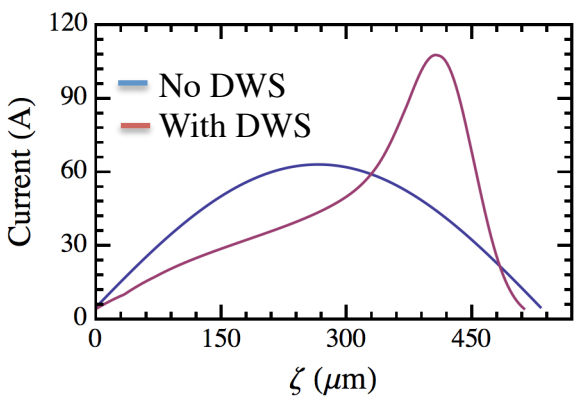
a) Measured CTR interferogram



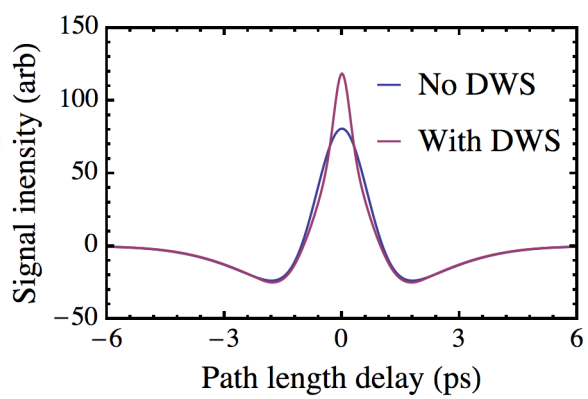
b) FFT of measured data



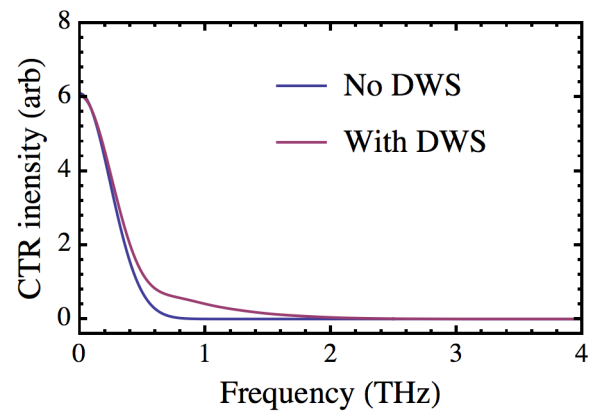
c) KK pulse reconstruction



d) Simulated Current profile



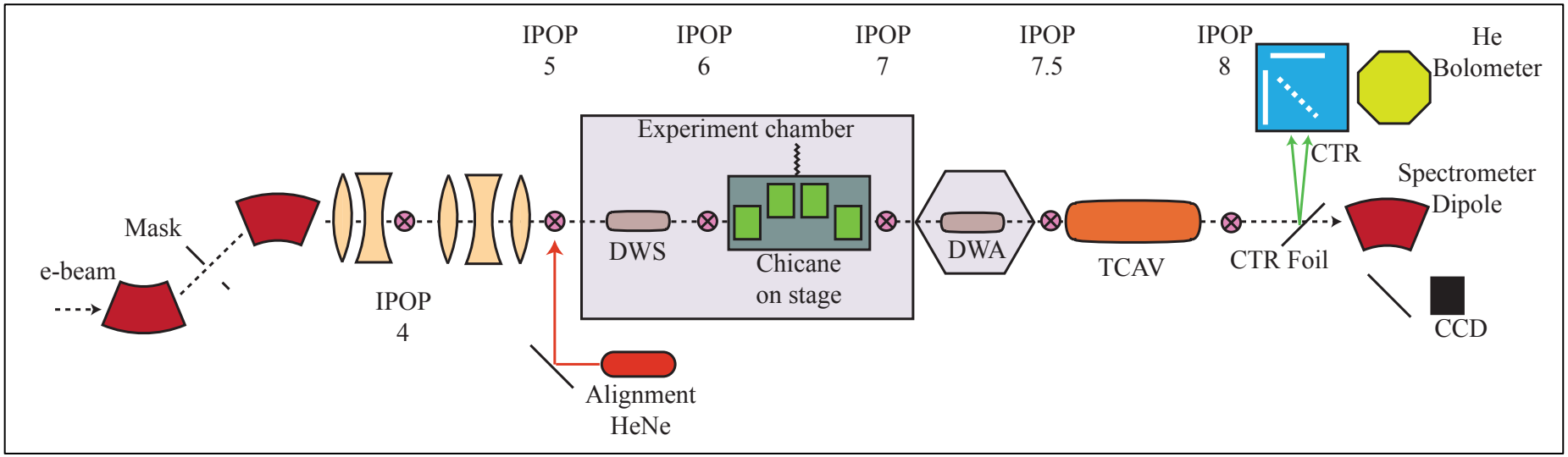
e) Simulated CTR interferogram



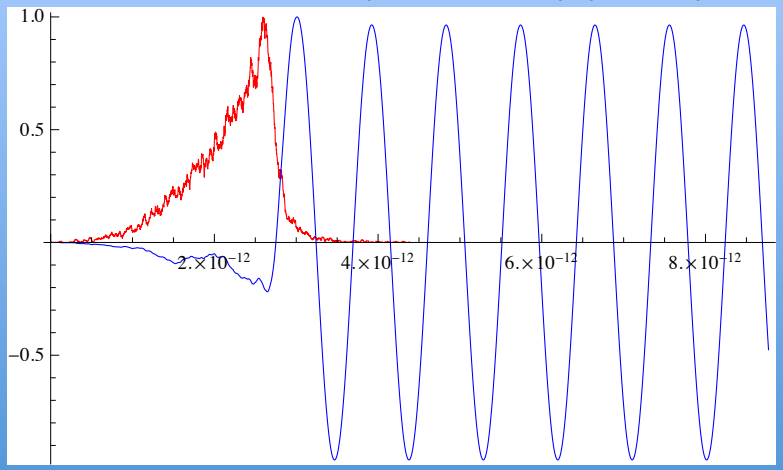
f) Simulated FFT from b)

G. Andonian, S. Barber, F. O'Shea, et al. to be submitted

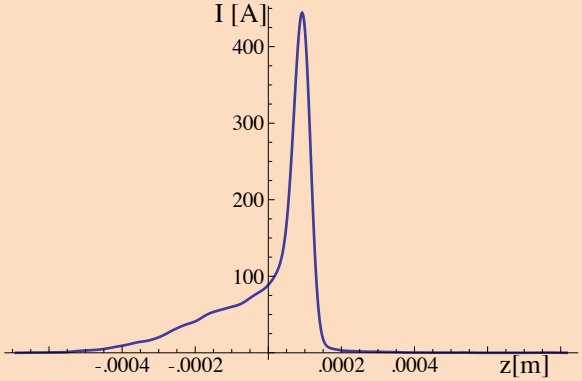
Next Experiment(s)



DWS+ DWA (f=1.1 THz) (TR~5)



Short pulse compressor (DWS + DWS)



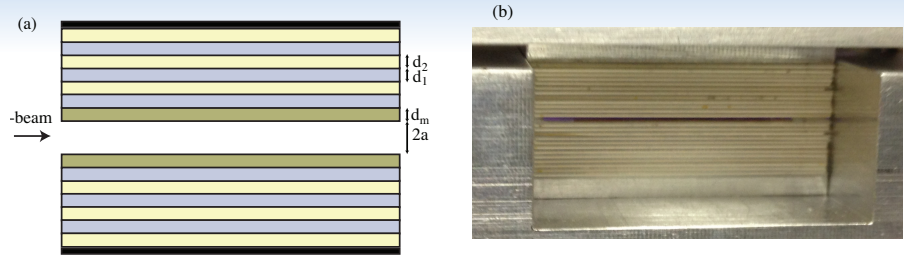
Outline

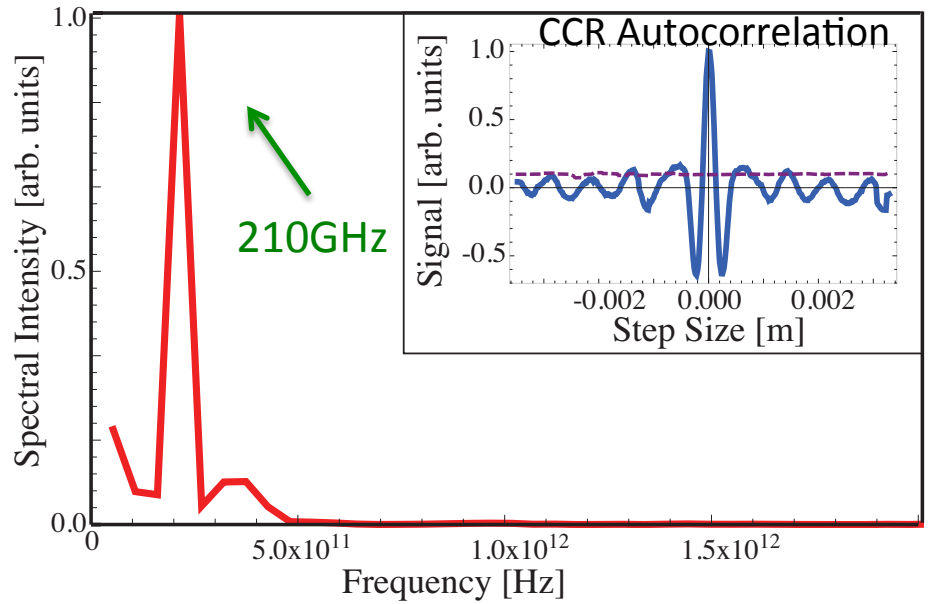
DWA experimental results from BNL ATF

1. Bunch profile shaping with wakefields
2. Single mode confinement using DWA with Bragg boundaries

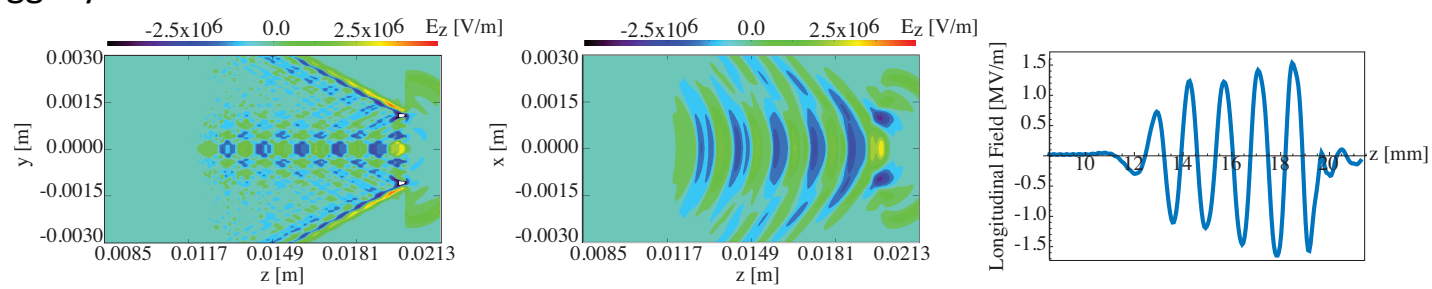
DWA with Bragg-reflector boundary

- Eliminate metal cladding
- Modal confinement
  - Constructive interference
  - Alternating dielectric layers
- DWA structure
  - SiO_2 matching layer
  - Planar geometry
  - Bragg layers SiO2, ZTA
  - Assembled at UCLA
- BNL ATF experiment
  - 50MeV, 100pC, σt~1ps
- Results
  - CCR interferometry
  - λ =1.4mm (210GHz)
  - Confirmed with simulation
- Upcoming measurements
  - Test Bragg stack vs slab
  - Test various Bragg layers





G. Andonian, et al., PRL 113, 264801 (2014)



Summary

- Demonstrated alternative beam shaping scheme
  - Next step is to measure TR
- Demonstrated mode confinement in Bragg DWA
- DWA is becoming a "real" tool for accelerator applications
  - Lots of design knobs for various applications

- Acknowledgements:
  - S. Barber, F. O'Shea, J. Rosenzweig, B. O'Shea, O. Williams, P. Hoang, B. Naranjo, D. Bruhwiler, A. Fukusawa, K. Fitzmorris, P. Favier, M. Fedurin, K. Kusche, C. Swinson
  - US DOE HEP

- Thank you!

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