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... for a brighter future

Survey of Advanced Dielectric Wakefield Accelerators

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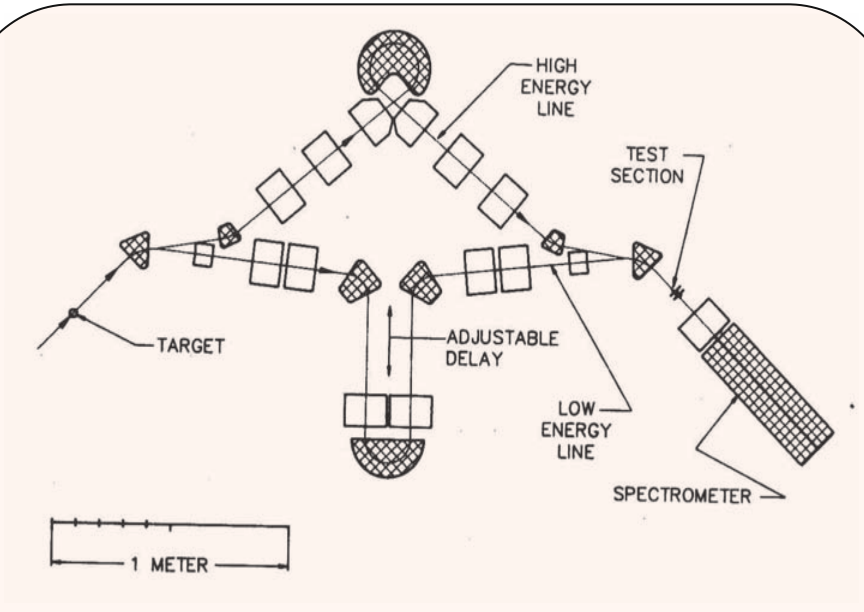
2007 Particle Accelerator Conference

Outline

- Dielectric Wakefield Acceleration experiments
  (more references in Proceedings paper)
- Argonne has been a major contributor (Euclid Techlabs)
- Yale / Omega-P / Columbia / Kharkov Institute collaboration
- UCLA / SLAC / USC / LLNL / Euclid Techlabs collaboration

First Demonstration of Dielectric Wakefield Acceleration

- Argonne Accelerator Test Facility (AATF) in late 1980s



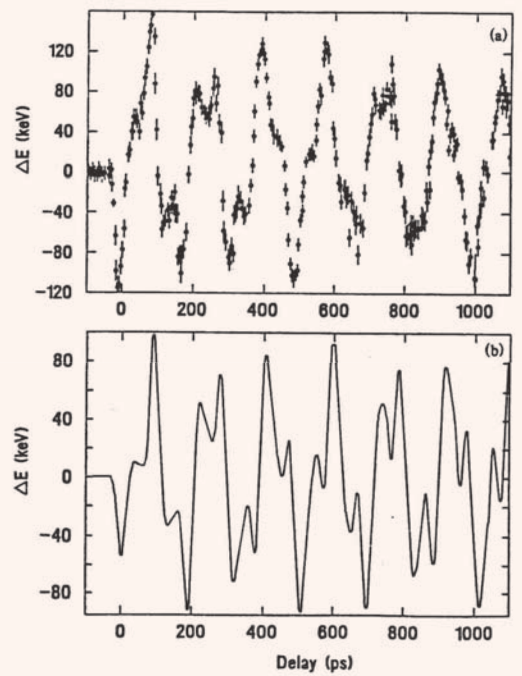
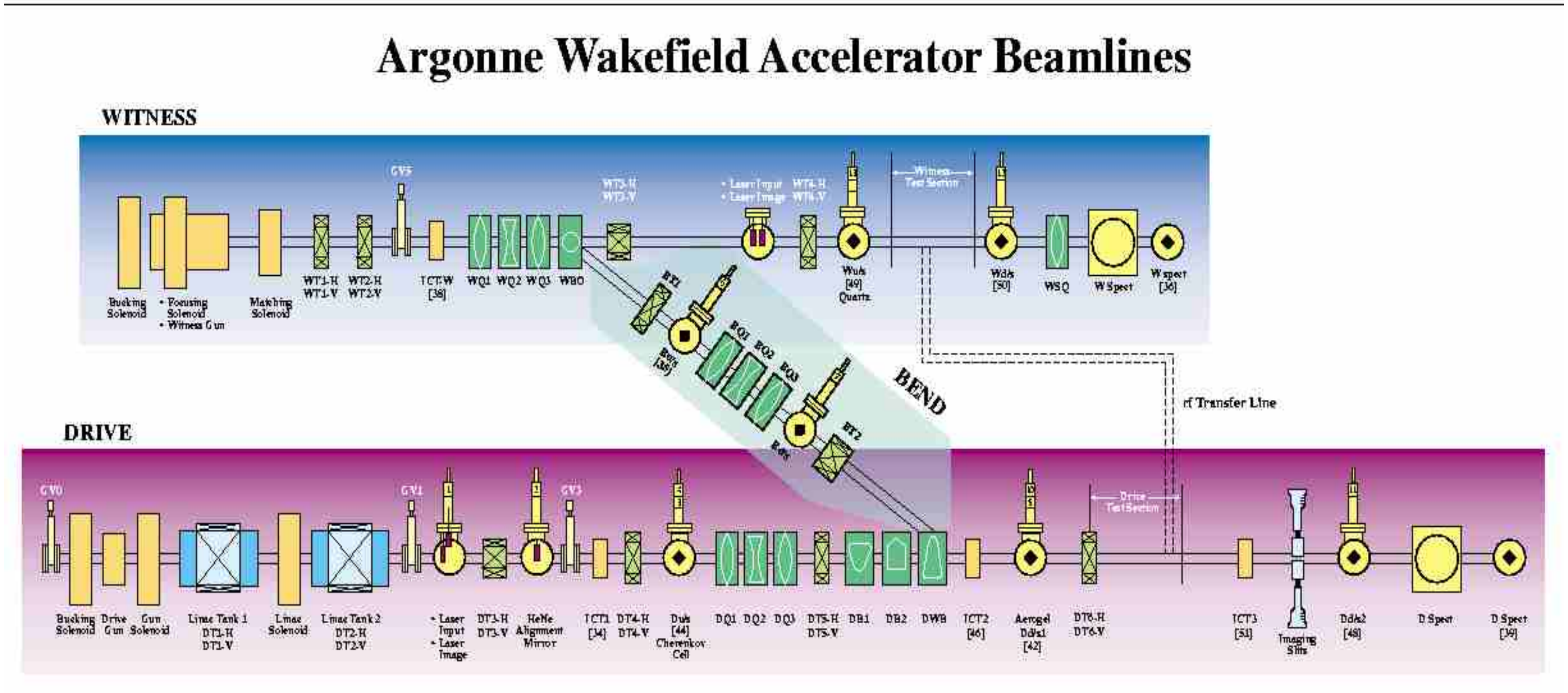


FIG. 3. Steatite scan: (a) measured and (b) calculated wake potential.

- 20 MeV drive beam (1 - 5 nC), and 16 MeV witness beam from the same thermionic RF gun
- Detailed mapping of wake potential (160 keV)
- Lesson: polymer based dielectrics charge up; ceramics are fine

Argonne Wakefield Accelerator – Original Configuration



- 14 MeV drive beam (10 – 100 nC), and 4 MeV witness beam from distinct photocathode RF guns
- Bunch train generation: four bunches of 10 nC

Wakefield Acceleration at AWA

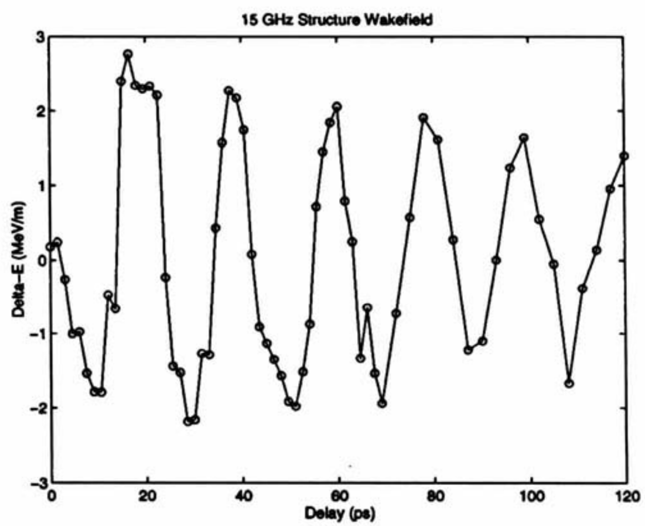
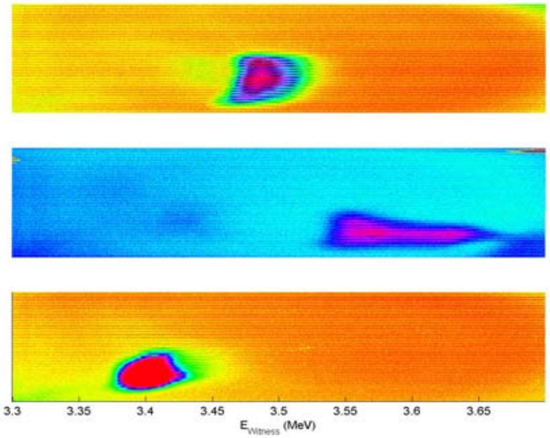
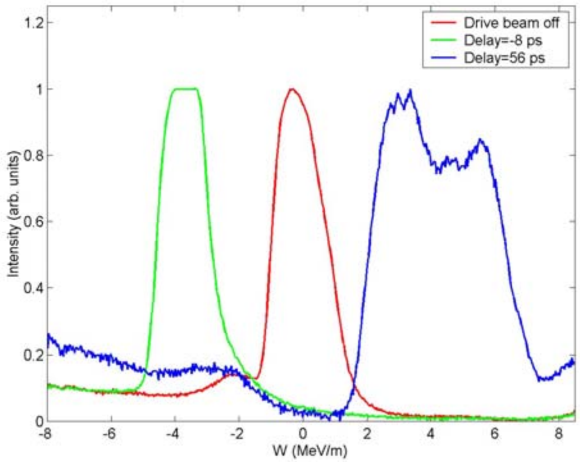


FIG. 3. Wake potential measurement for 15 GHz dielectric structure. Each data point is the change in the bend view centroid of the witness beam at the spectrometer 60° port.

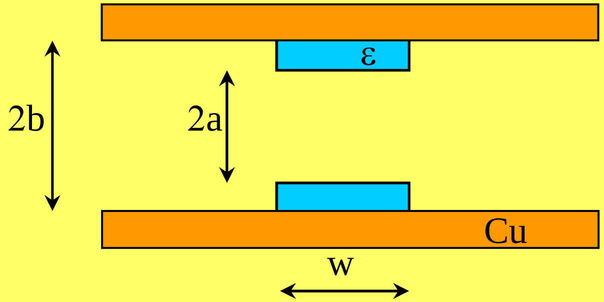




- Collinear wakefield acceleration: 15 MV/m
- First TBA with dielectric loaded structures: 3.5 MV/m deceleration in Stage I, 7 MV/m acceleration in Stage II

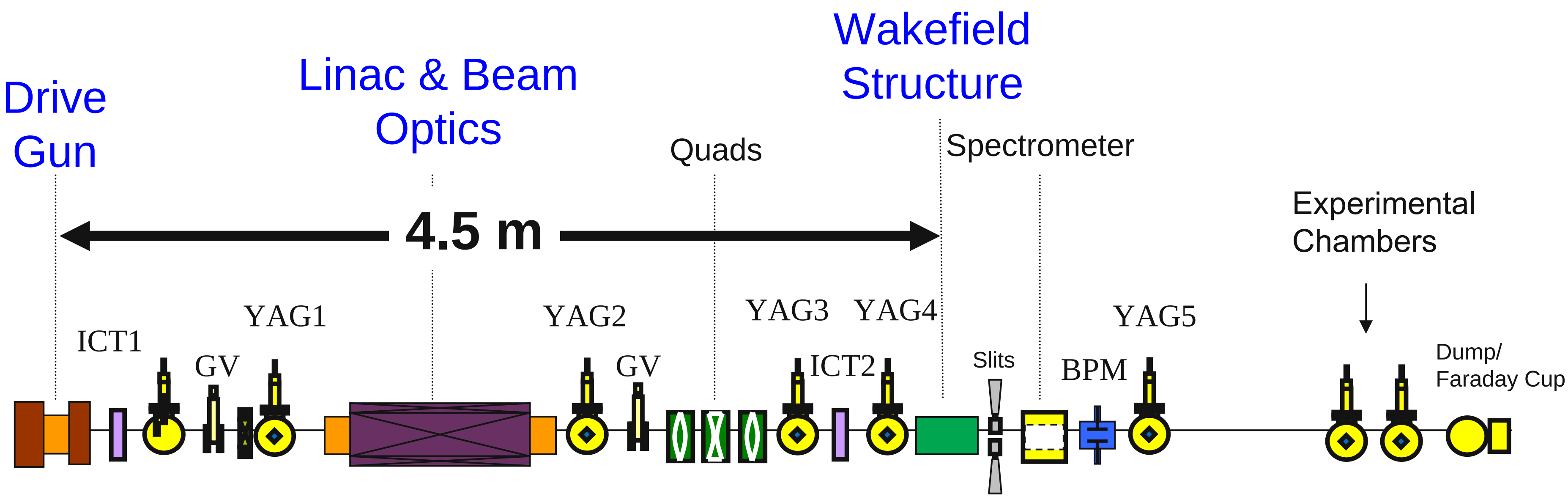
91 GHz Planar Dielectric Wakefield Accelerator at SLAC

M.E. Hill, C. Adolphsen, W. Baumgartner, R.S. Callin, X.E. Lin, M. Seidel, T. Slaton, D.H. Whittum, PRL **87**, 2001



- Planar dielectric structure in a ring resonator circuit.
- Dielectric slab: 0.3 × 0.8 × 25.4 mm^3 alumina, ε = 9.5
- Structure: a = 360 μm, b = 660 μm, w = 800 μm
- Beam: 300 MeV, 100 ns, 0.5 A, 11.4 GHz (×8)
- Measurements: 20 MV/m, 200 kW, 42 MΩ/m

New AWA Drive Beamline



Single bunch operation

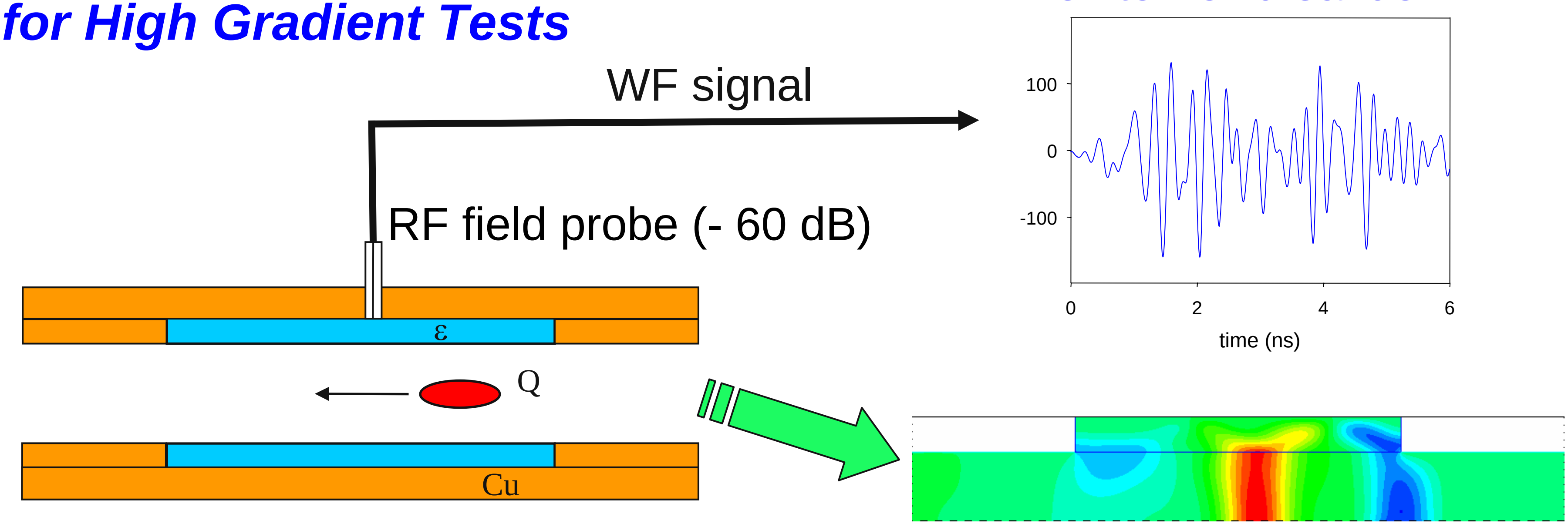
- Q = 1-100 nC (reached 150 nC)
- 15 MeV, 2 mm bunch length (rms), emittance < 200 mm mrad (at 100 nC)
- High Current: ~10 kA

Bunch train operation

- 4 bunches x 10 nC
- 64 bunches x 50 nC → 50 ns long (future)

Experimental Setup for High Gradient Tests

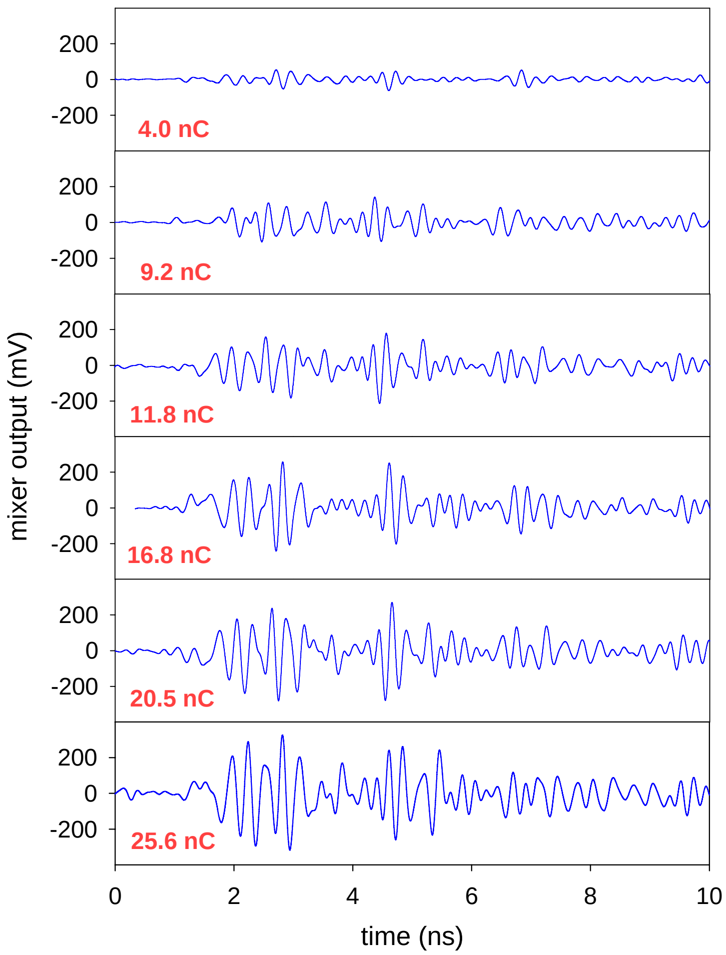
Monitor for breakdown

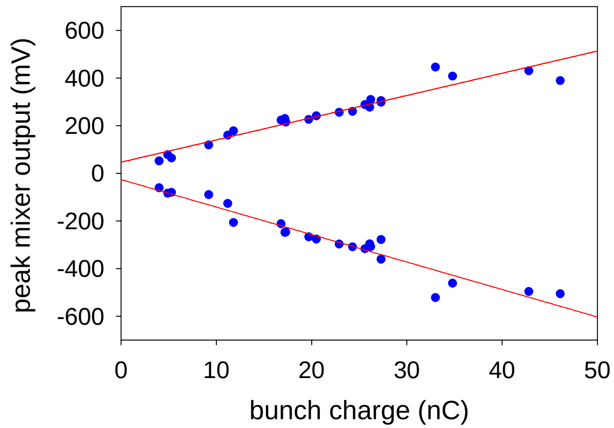


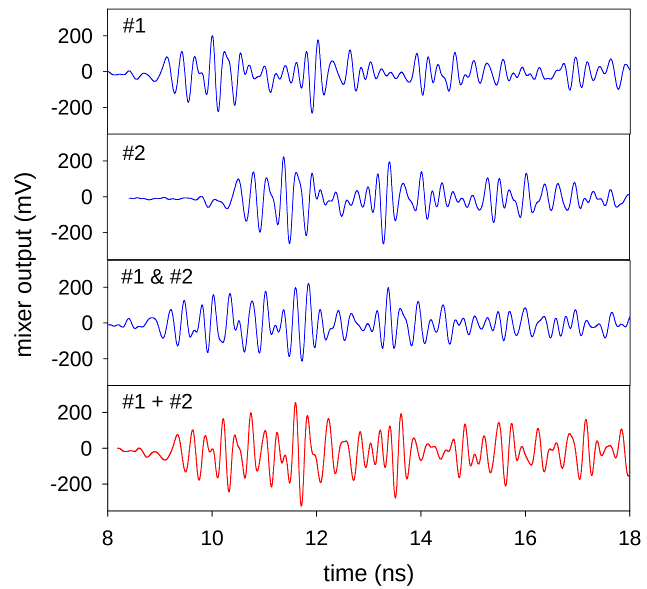
Infer Gradients from MAFIA

SW Structure	#1 C10-102	#2 C10-23	#3 C5.5-28	#4 Q3.8-25.4
Material	Cordierite	Cordierite	Cordierite	Quartz
Dielectric constant	4.76	4.76	4.76	3.75
Freq. of TM01n	14.1 GHz	14.1 GHz	9.4 GHz	8.6 GHz
Inner radius	5 mm	5 mm	2.75 mm	1.9 mm
Outer radius	7.49 mm	7.49 mm	7.49 mm	7.49 mm
Length	102 mm	23 mm	28 mm	25.4 mm
Wakefield Gradient	0.45 MV/m/nC	0.5 MV/m/nC	0.91 MV/m/nC	1.33 MV/m/nC

Wakefield Measurements: Structure #1 (C10-102)



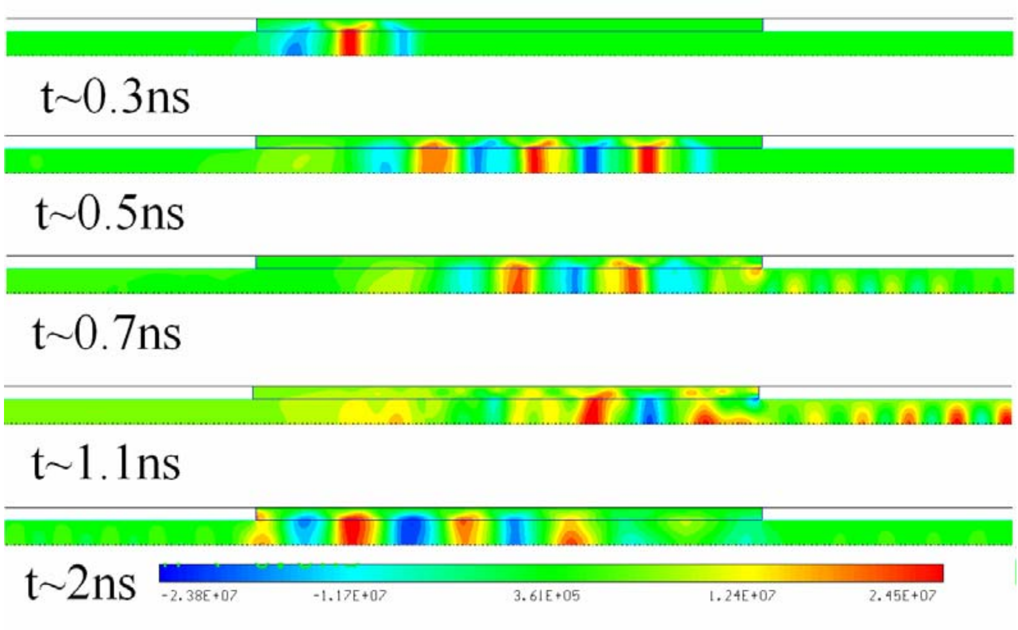




46 nC → 21 MV/m

☺

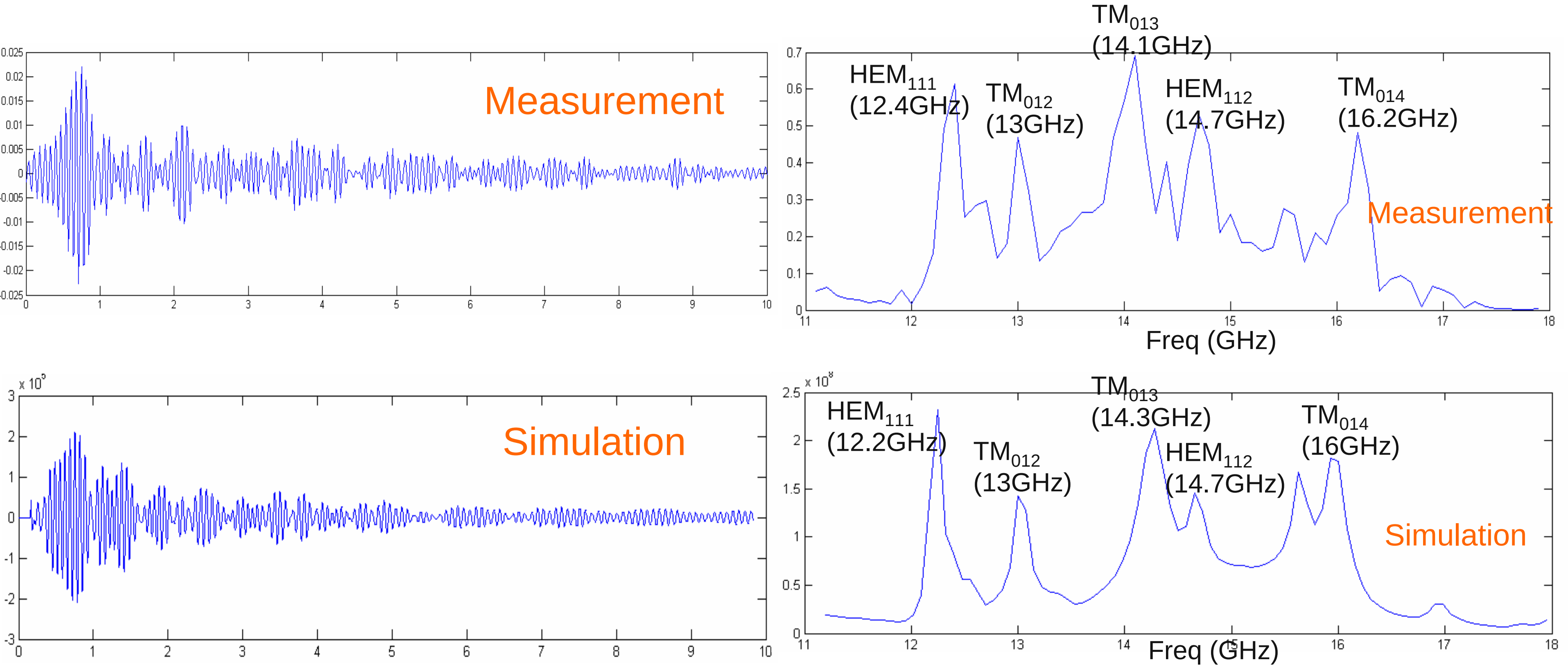
MAFIA Simulation of Structure #1 (C10-102)



Snapshots of wakefield amplitude

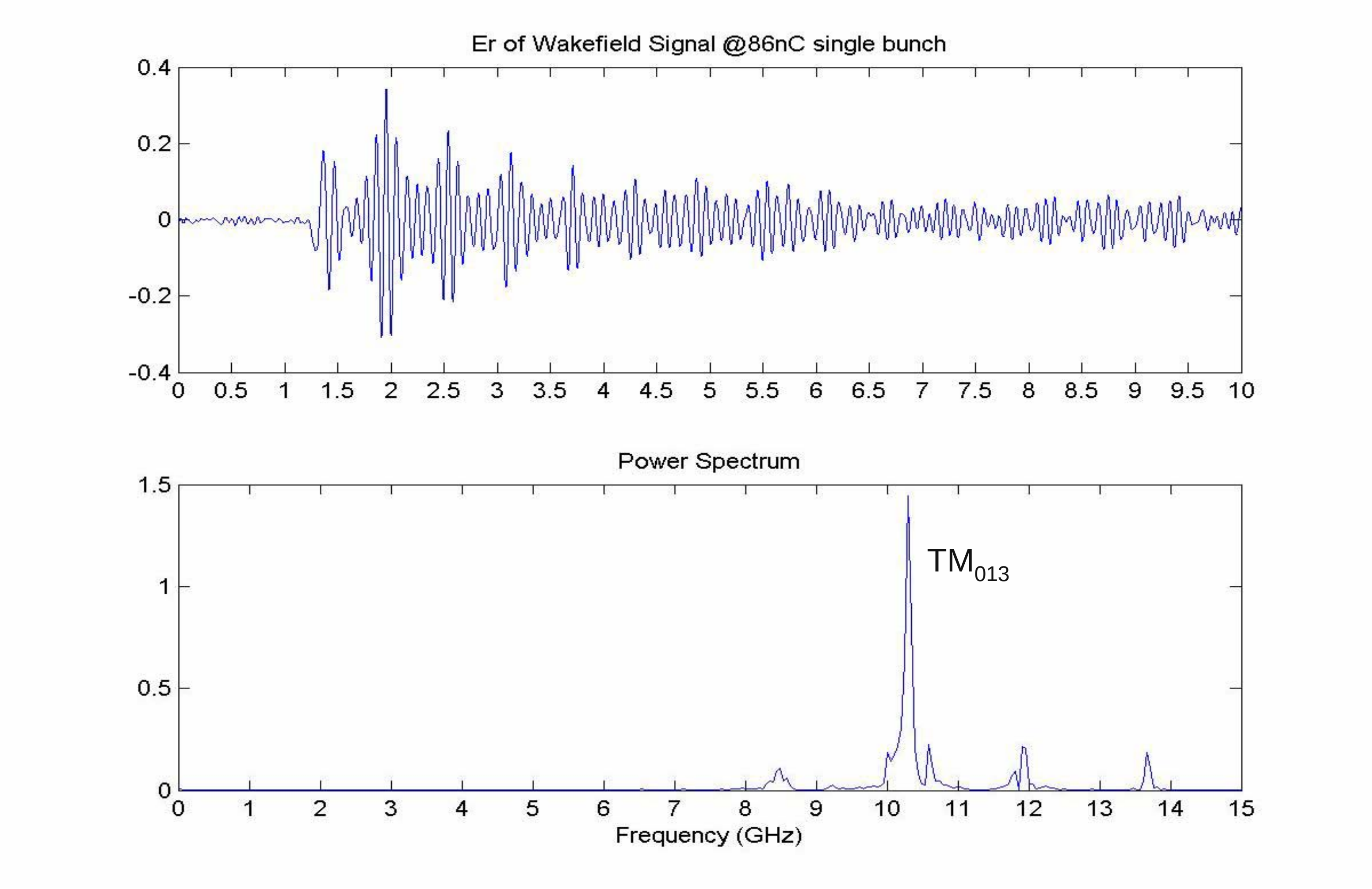
Wakefield Measurements: Structure #2 (C10-23)

Measured and simulated E_r probe signals



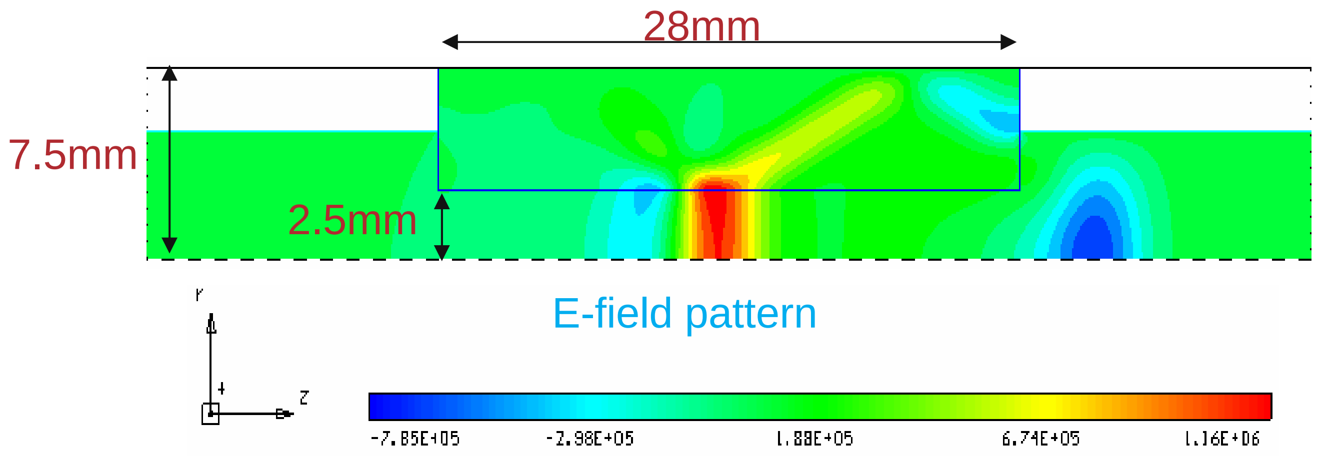
86 nC → 43 MV/m

Wakefield Measurements: Structure #3 (C5.5-28)

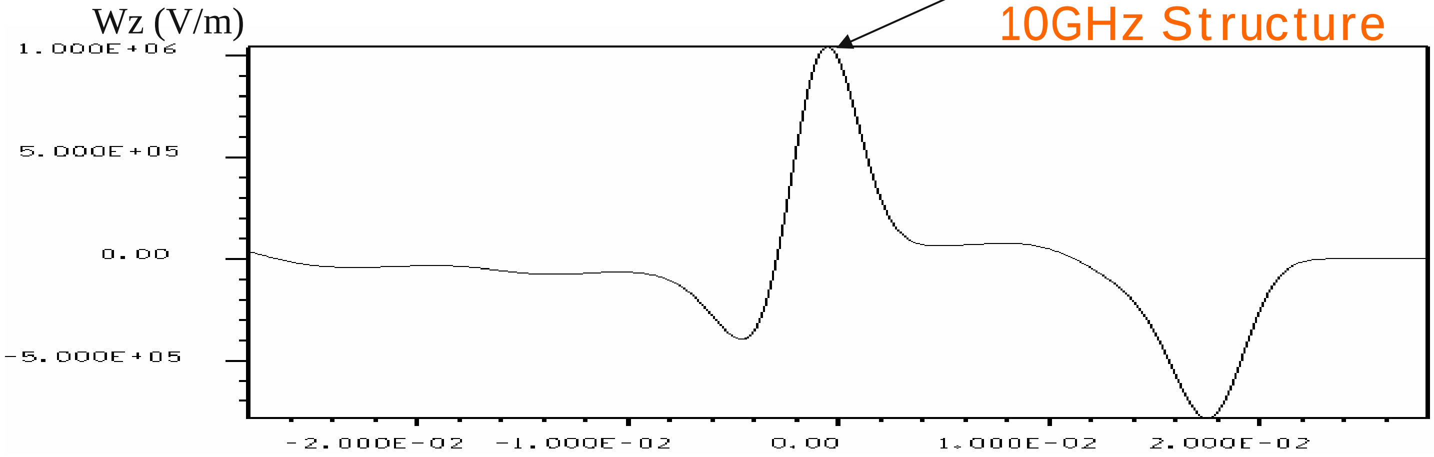


86 nC → 78 MV/m ☺

MAFIA Simulation of Structure #3 (C5.5-28)

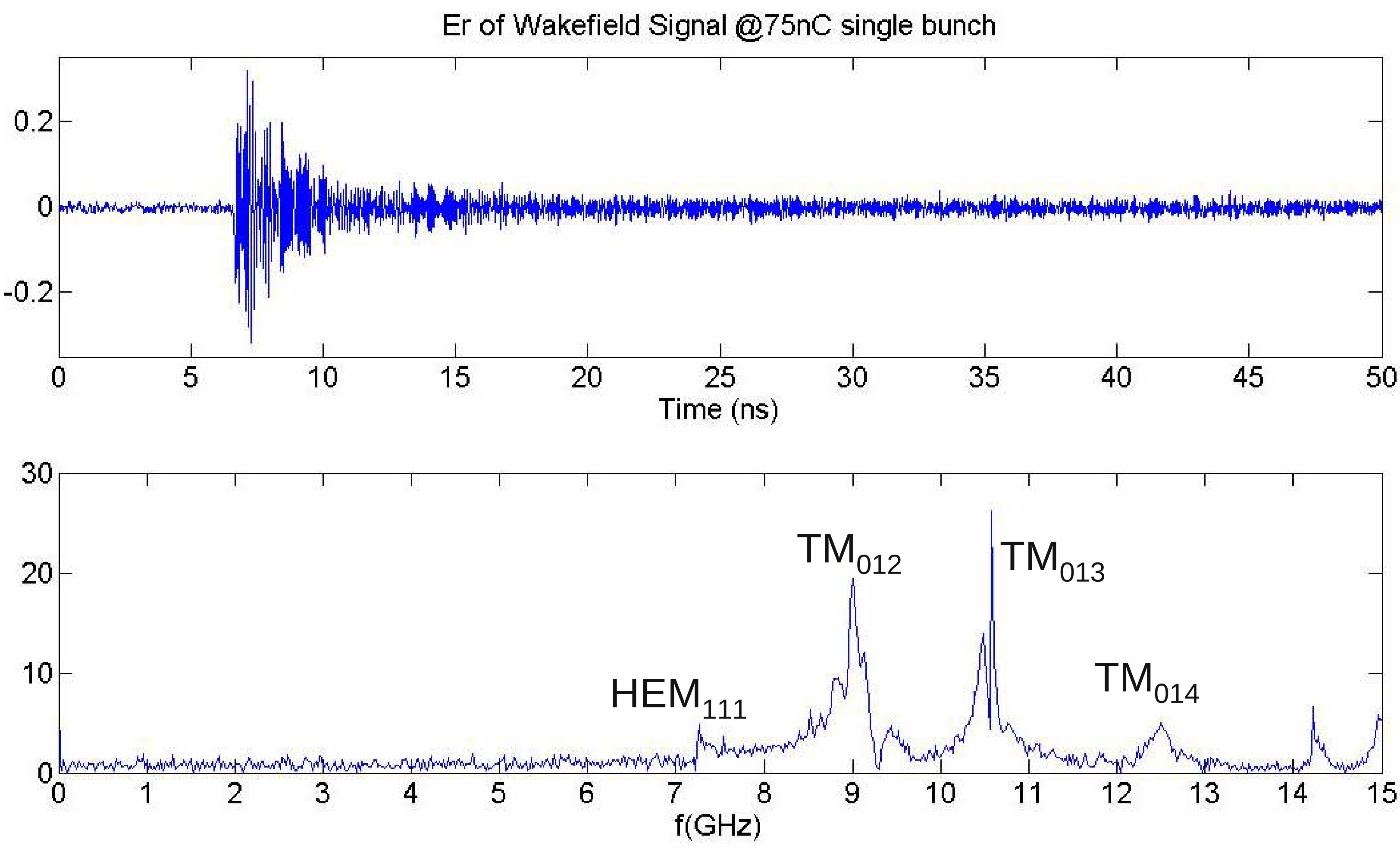


E-field pattern



Wz > 1MV/m @ 1nC for 10GHz Structure

Wakefield Measurements: Structure #4 (Q3.8-25.4)

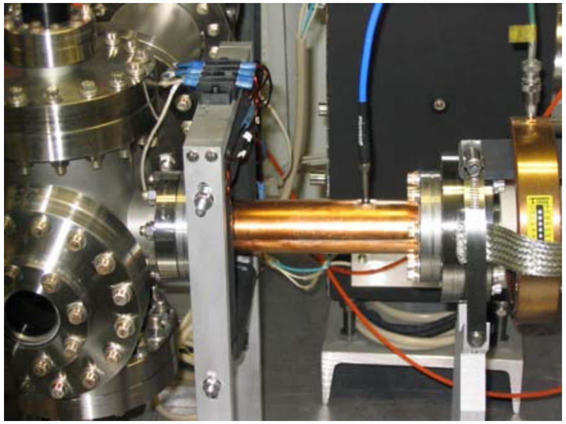


75 nC → 100 MV/m

☺ ☺

Dielectric Loaded Structures at AWA: Steadily Increasing Accelerating Gradients

■ The 1990s:	~10 MV/m
■ Structure #1 (Summer 2005):	21 MV/m
■ Structure #2 (Winter 05/06):	43 MV/m
■ Structure #3 (Summer 2006):	78 MV/m
■ Structure #4 (Spring 2007):	100 MV/m

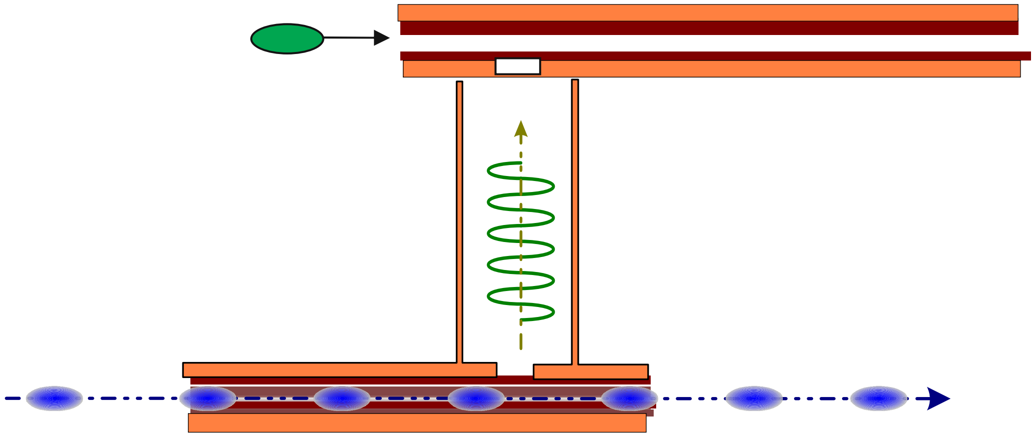


Next Steps:

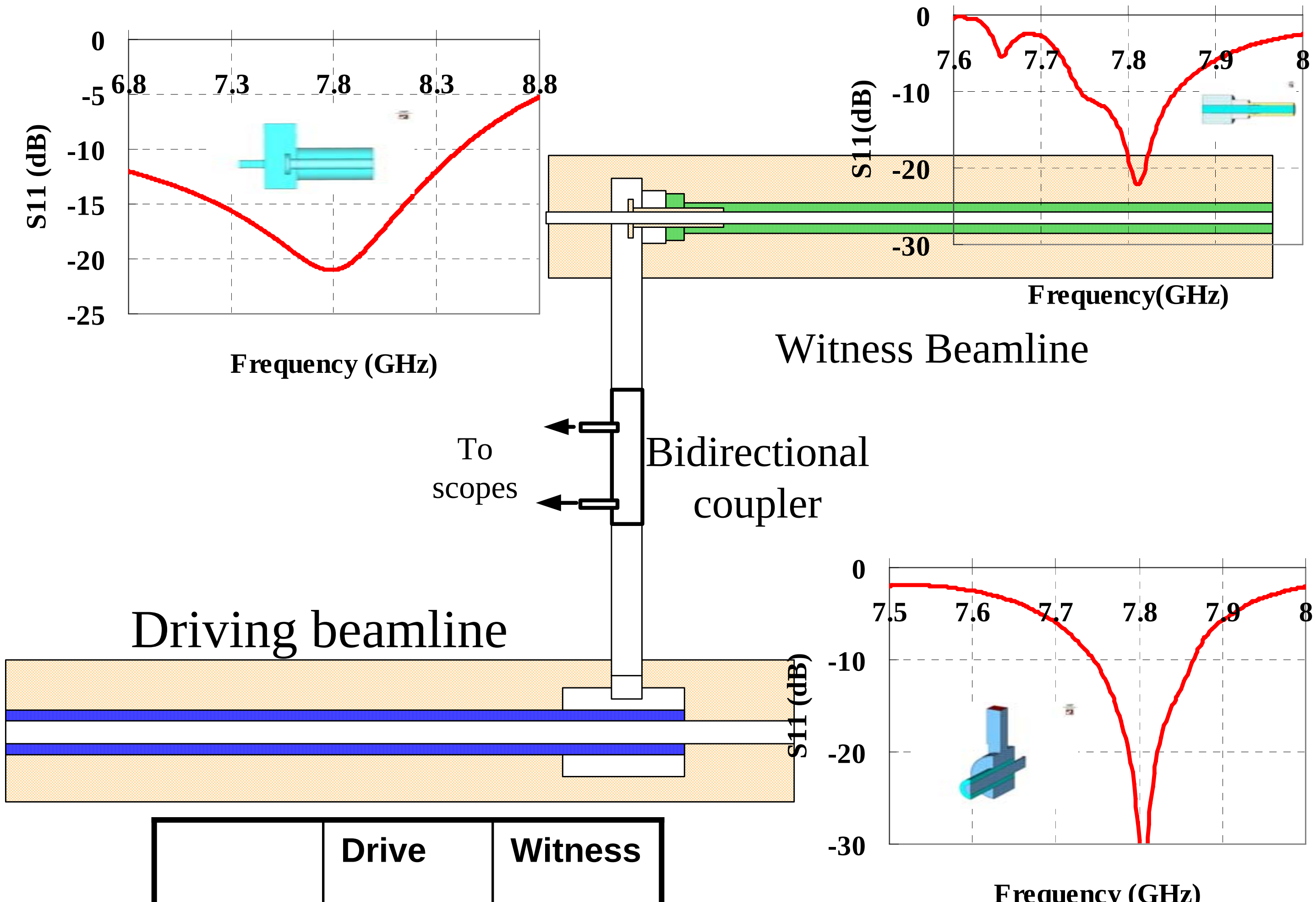
- Test more structures
- Cesium telluride photocathodes (long, high charge bunch trains)
- Additional klystron (thanks to B. Carlsten, S. Russell, and DOE !!)
- Complete new RF gun
- Restore two-beam-accelerator capability

An Example of Two-Beam Accelerator (Future Goal)

- Drive beam: 64 bunches of 50 nC, each separated by one RF period, generating a 50 ns long RF pulse.
- Stage I (28 cm long): 2a=11 mm, 2b=22 mm, ε = 4.6, 45 MV/m deceleration field, generating 500 MW (flat top).
- Stage II (85 cm long): 2a= 6mm, 2b= 11 mm, ε = 20, 112 MV/m acceleration field, yielding a total acceleration of 95 MeV.

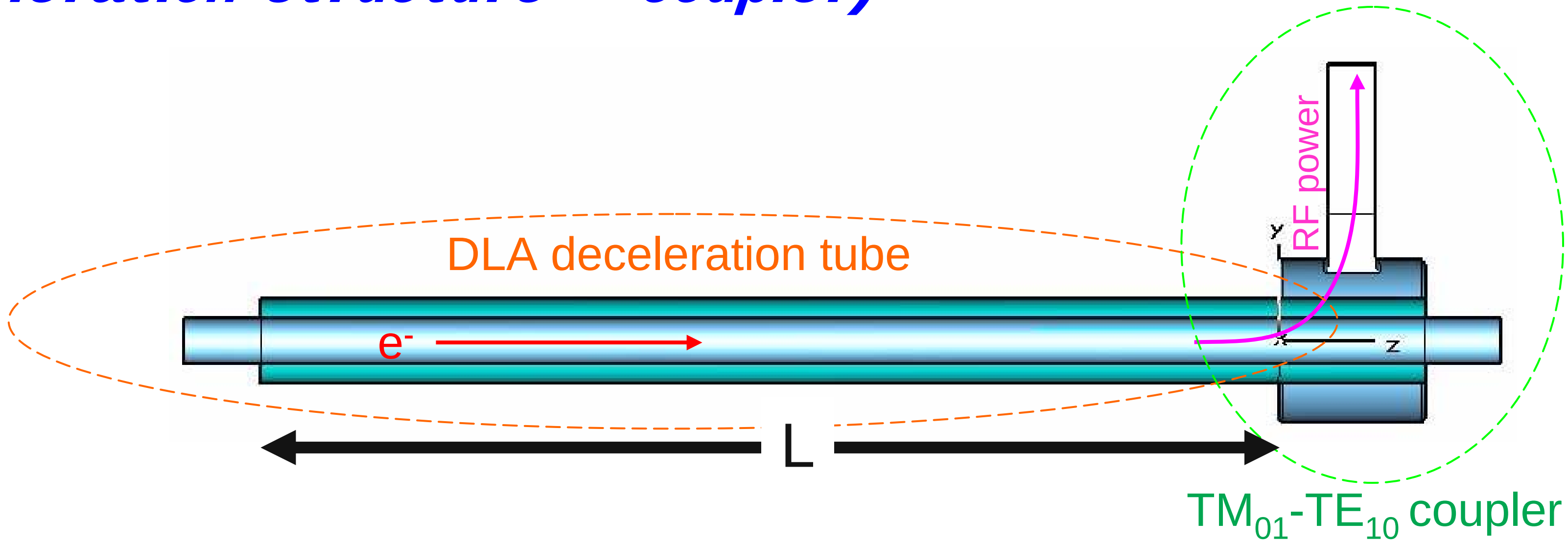


Two Beam Accelerator Design



	Drive	Witness
a (mm)	6.02	3.00
b (mm)	11.17	5.406
ε_r	4.6	20

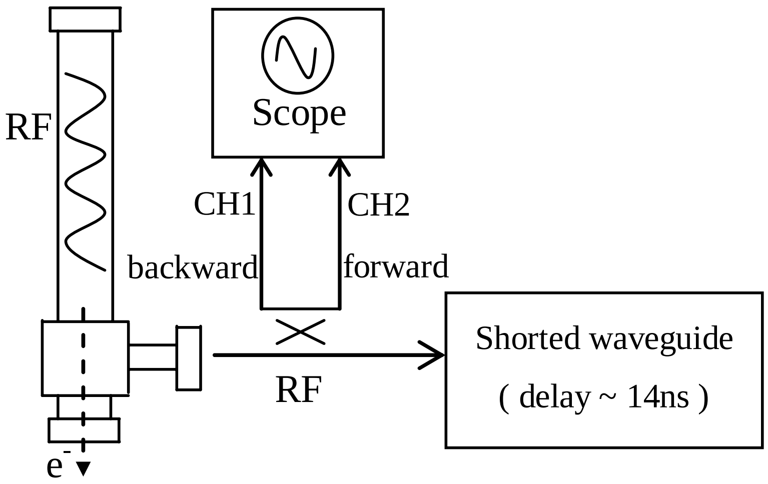
Development of a 7.8 GHz Power Extractor (deceleration structure + coupler)

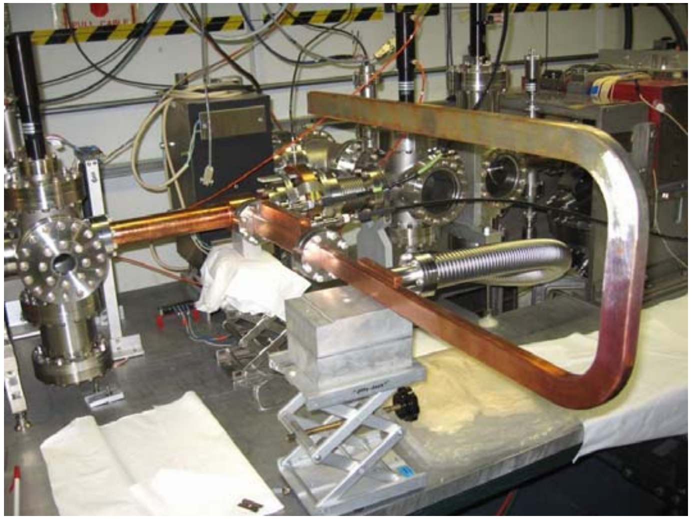


f_{RF} GHz	*ID* mm	*OD* mm	*L* mm	ε_r	β_g	t_d ns	δ_d 10^{-4}	Q_w	*Q*	[*r/Q*] kΩ/m	r_{sh} MΩ/m
7.8	12.04	22.34	266	4.6	0.23	2.9	5	8777	2745	6.09	16.7

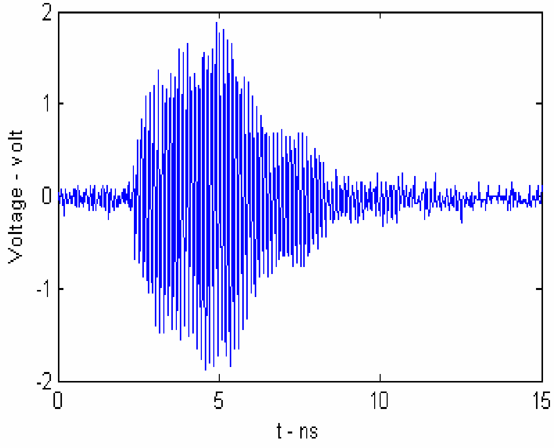
dielectric = cordierite

7.8GHz Power Extractor

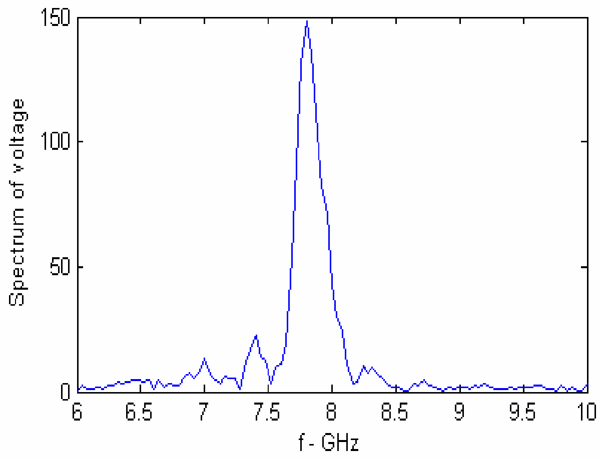




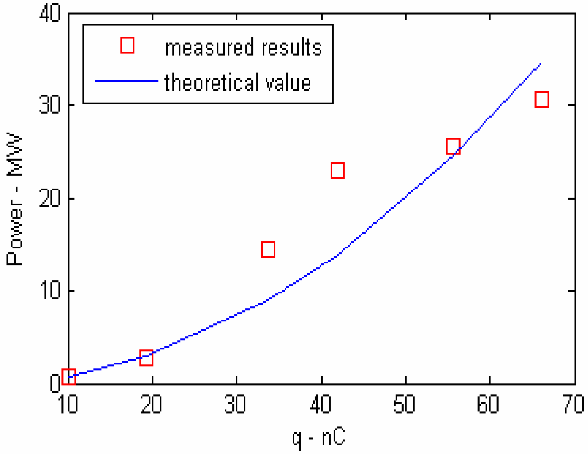
Detected voltage signal
(q = 66nC, σ_z=2mm)



Spectrum of the signal
(q = 66nC, σ_z=2mm)

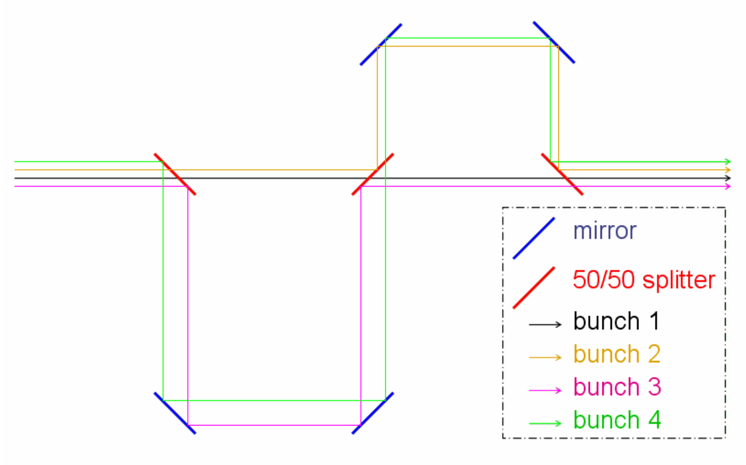


Generated power vs. charge
(single bunch test)

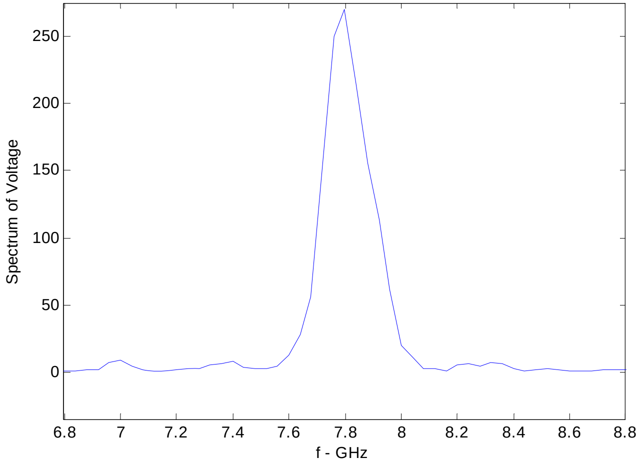


Bunch Train through Power Extractor

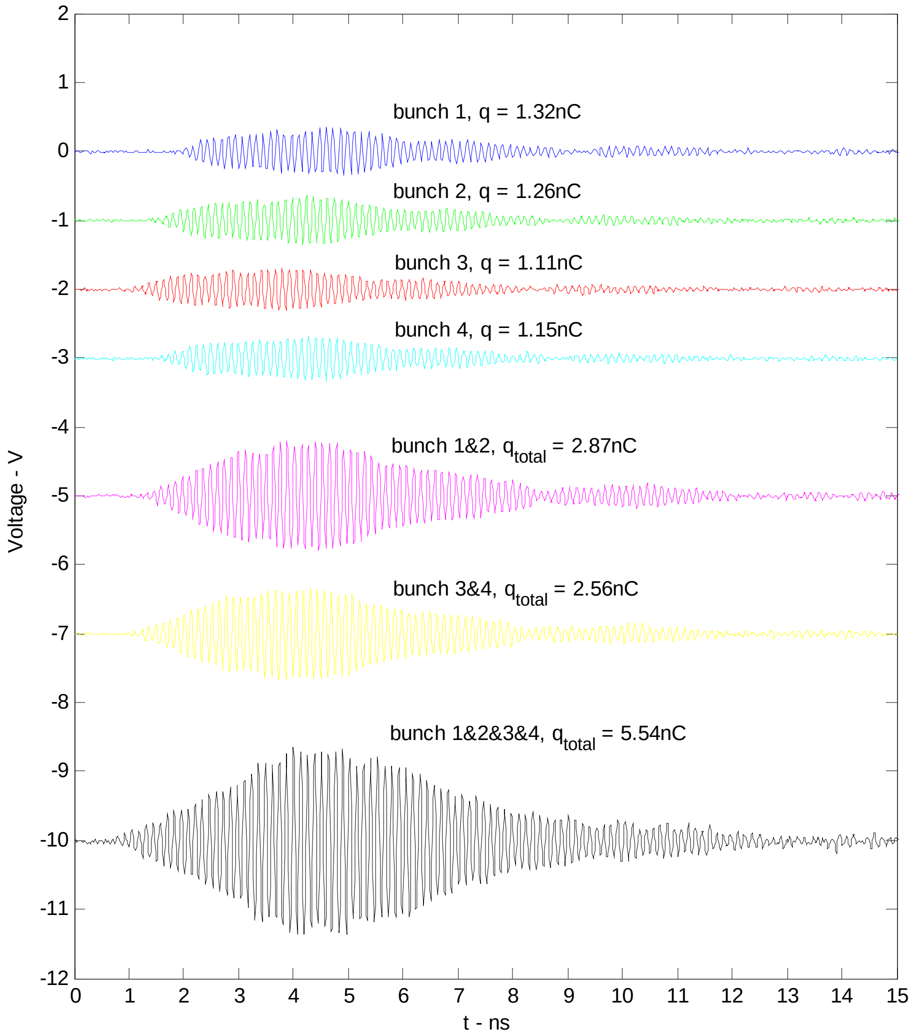
Laser beam splitter



Spectrum of voltage signal



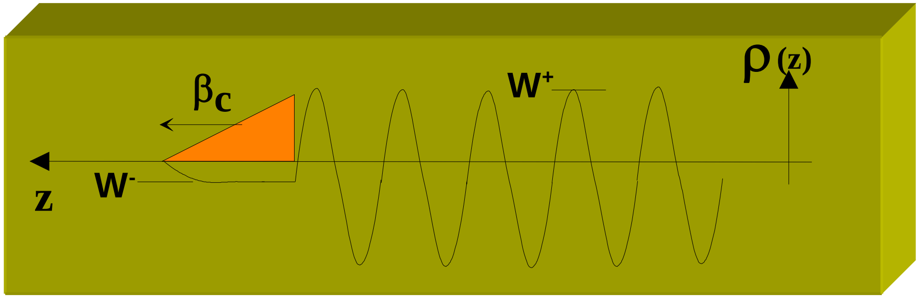
Wakefield superposition observed



*Wakefield Transformer Ratio Enhancement Experiment at AWA**

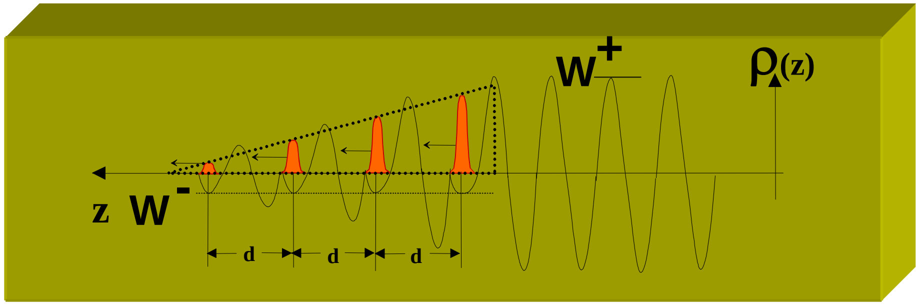
- Transformer ratio limited: Wakefield theorem says: A trailing beam can not gain more than twice of the drive beam peak energy loss in a collinear wakefield scheme if the drive beam is longitudinal symmetric distributed, which results in the accelerated beam can not gain much due to the limited drive beam energy
- The asymmetric bunch distribution will beat R<2 limit---the principal goal of this experiment is to demonstrate this idea.

Scheme I---Single Triangular Bunch



Reference: Bane et. al., IEEE Trans. Nucl. Sci. NS-32, 3524 (1985)

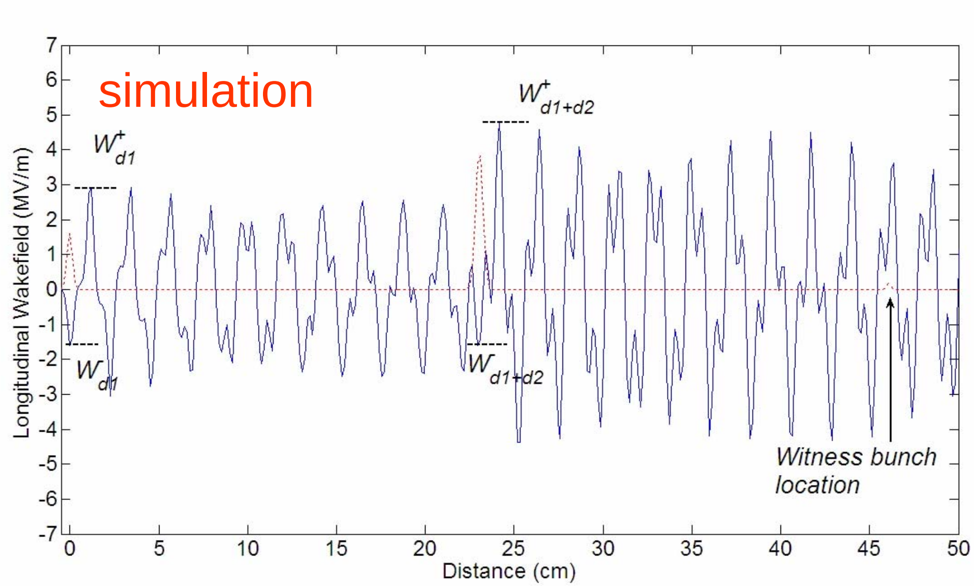
Scheme II---Ramped Bunch Train

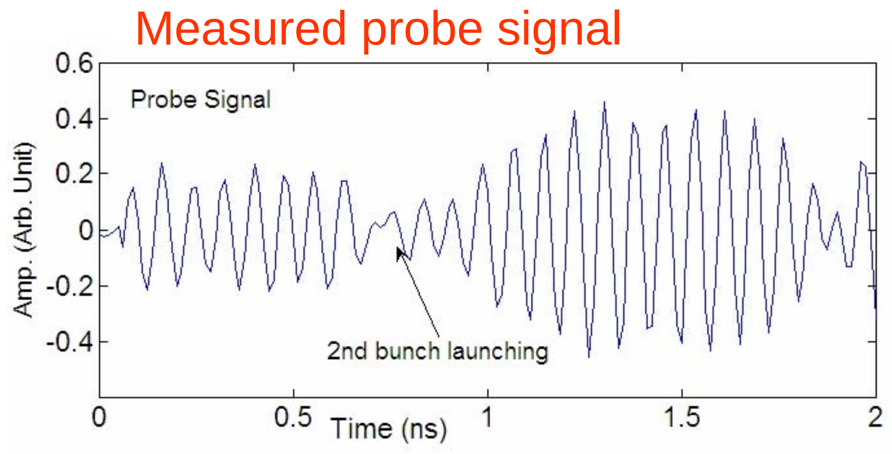


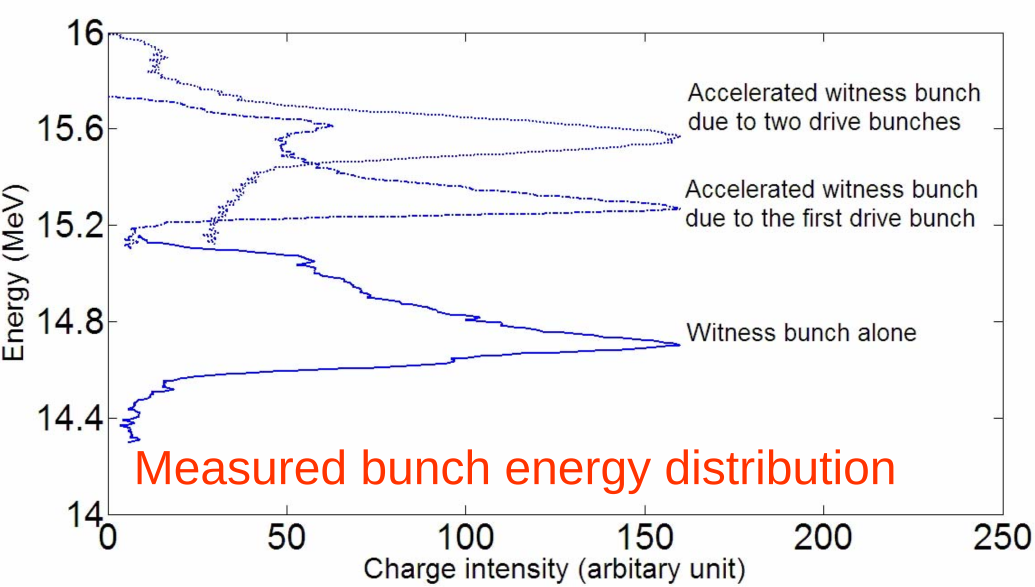
Reference: Schutt et. al., Nor Ambred, Armenia, (1989)

** This work is a collaboration with Euclid Techlabs, LLC. The results were published in Phys. Rev. Lett. 98 (2007) 144801. This work was supported by DoE SBIR funding.*

Measurements







measurement ⟹ $$\frac{W^{-}_{d1+d2}}{W^{-}_{d1}} = 1$$

measurement ⟹ $$\frac{W^{+}_{d1+d2}}{W^{+}_{d1}} = 1.31 \pm 0.13$$

This is measured wakefield transformer ratio enhancement! Transform Ratio R was enhanced for two ramped bunches is 3 in theory and 2.3 in measurement.

HG two-beam wake field accelerator using a two-channel rectangular dielectric structure*

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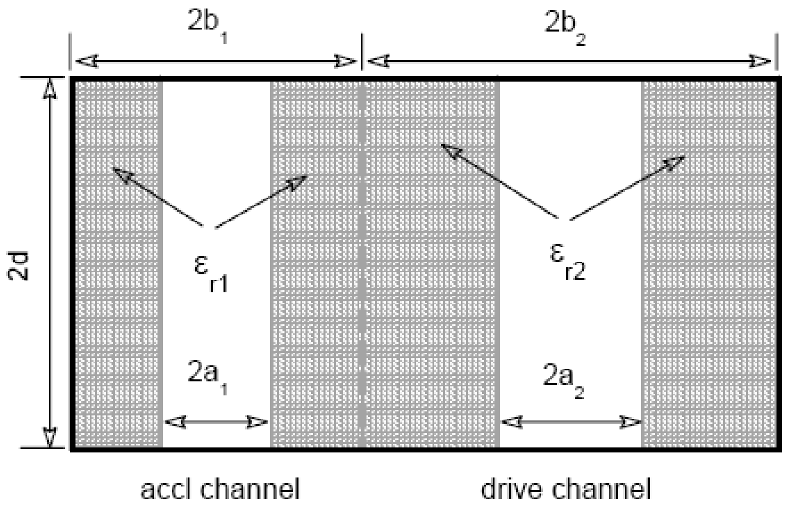
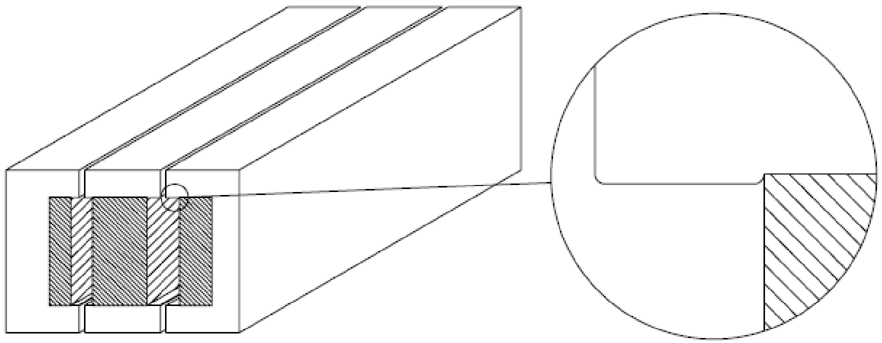
G.V. Sotnikov[2,4], C.B. Wang

[1] *Yale University Beam Physics Laboratory*
[2] *Omega-P, Inc.*
[3] *Columbia University*
[4] *Kharkov Institute of Physics and Technology*

**Research sponsored by US DoE, DHEP*





Features of a two-beam dielectric wake field accelerator (DWFA):

- High adjustable transformer ratio $T \gg 2$;
- Wall slots and bunch location that may help suppress HOM's;
- Simple but precise fabrication of planar dielectric elements;
- Continuous coupling of energy from drive to accelerated bunch;
- No need for coupling/transfer structures;
- Continuous pumpout of narrow channels through wall slots;
- High accelerating fields in the single bunch mode.

E-169: Wakefield Acceleration in Dielectric Structures

A proposal for experiments at the SABER facility

H. Badakov[α], M. Berry[β], I. Blumenfeld[β], A. Cook[α], F.-J. Decker[β], M. Hogan[β], R. Ischebeck[β], R. Iverson[β], A. Kanareykin[ε], N. Kirby[β], P. Muggli[γ], J.B. Rosenzweig[α], R. Siemann[β], M.C. Thompson[δ], R. Tikhoplav[α], G. Travish[α], D. Walz[β]

[α]*Department of Physics and Astronomy, University of California, Los Angeles*

[β]*Stanford Linear Accelerator Center*

[γ]*University of Southern California*

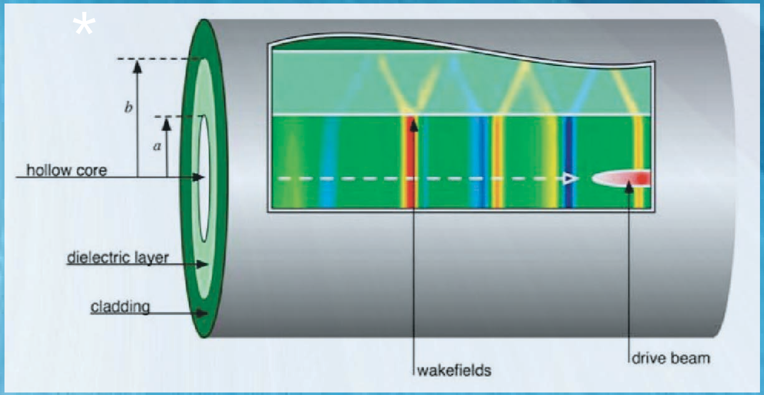
[δ]*Lawrence Livermore National Laboratory*

[ε]*Euclid TechLabs, LLC*

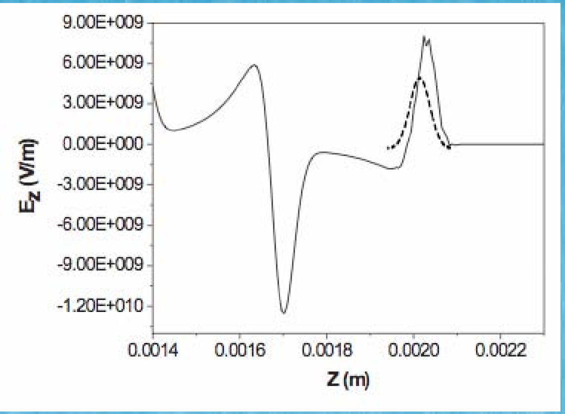
Collaboration spokespersons

Dielectric Wakefield Accelerator

Overview



- Design Parameters $a,\ b,\ L_d,\ \varepsilon\quad N_b,\ \sigma_z$



Ez on-axis, OOPIC

- Electron bunch (β ≈ 1) drives ***Cerenkov wake*** in cylindrical dielectric structure
  - Variations on structure features
  - Multimode excitation
- Wakefields accelerate trailing bunch
  - Mode wavelengths

$$\lambda_n \approx \frac{4(b-a)}{n}\sqrt{\varepsilon-1}$$

  - Peak decelerating field

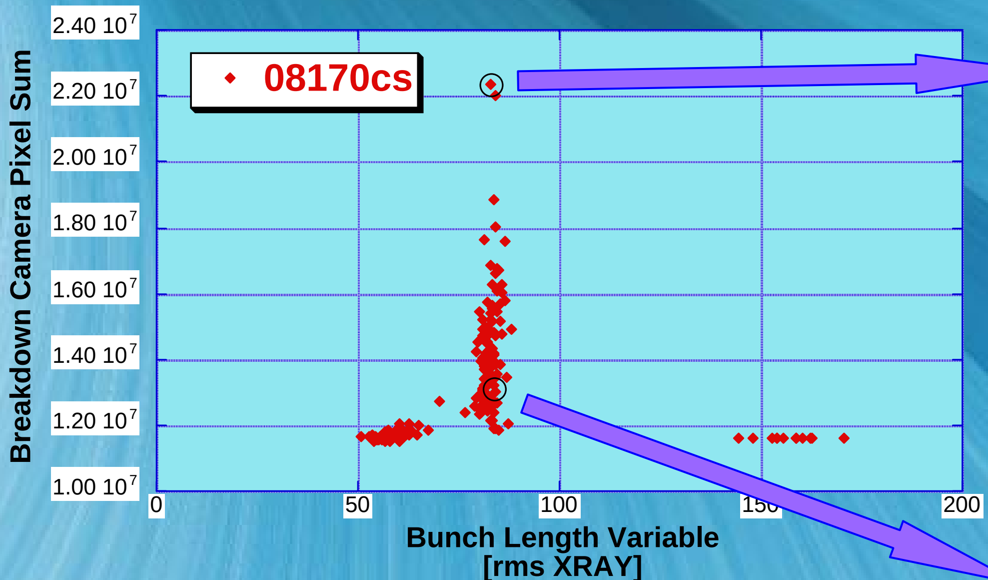
$$eE_{z,dec} \approx \frac{-4N_b r_e m_e c^2}{a\left[\sqrt{\frac{8\pi}{\varepsilon-1}}\varepsilon\sigma_z + a\right]}$$

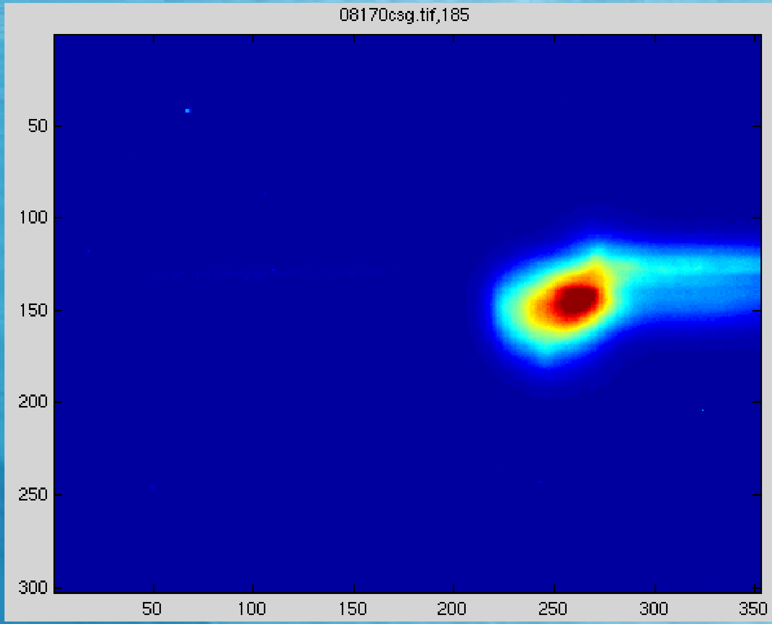
Extremely good beam needed

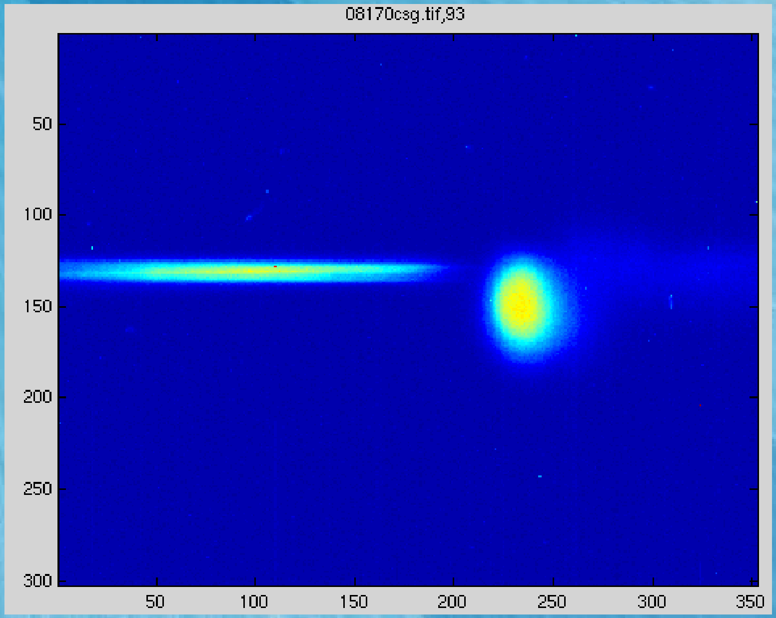
  - Transformer ratio

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

Breakdown Threshold Observation







- Goal: breakdown studies
  - Al-clad fused silica fibers
    - ID 100/200 μm, OD 325 μm, *L*=1 cm
  - Avalanche v. tunneling ionization
  - Beam parameters indicate ≤
    - 30 GeV, 3 nC, $\sigma_z \geq 20$ μm

Significant and steady progress being made in the development of Dielectric Wakefield Accelerators!