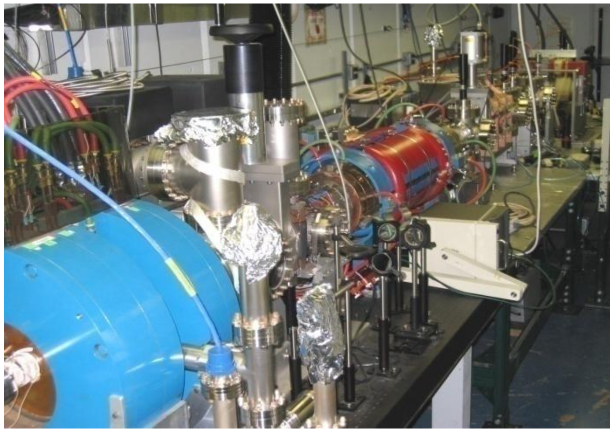
DIELECTRIC BASED HG STRUCTURES: POWER EXTRACTION, TUNABILITY AND ENERGY TRANSFER EFFICIENCY

A. Kanareykin

Euclid Techlabs LLC in collaboration with AWA,ANL

ANL/Euclid Techlabs Collaboration on Dielectric Wakefield Acceleration



Euclid Techlabs: C.Jing, P.Schoessow, S.Antipov, F.Gao and A.Kanareykin

Argonne National Lab: M.Conde, J.G.Power, R.Conecny, Z.Yusof and W.Gai.

Euclid Techlabs LLC

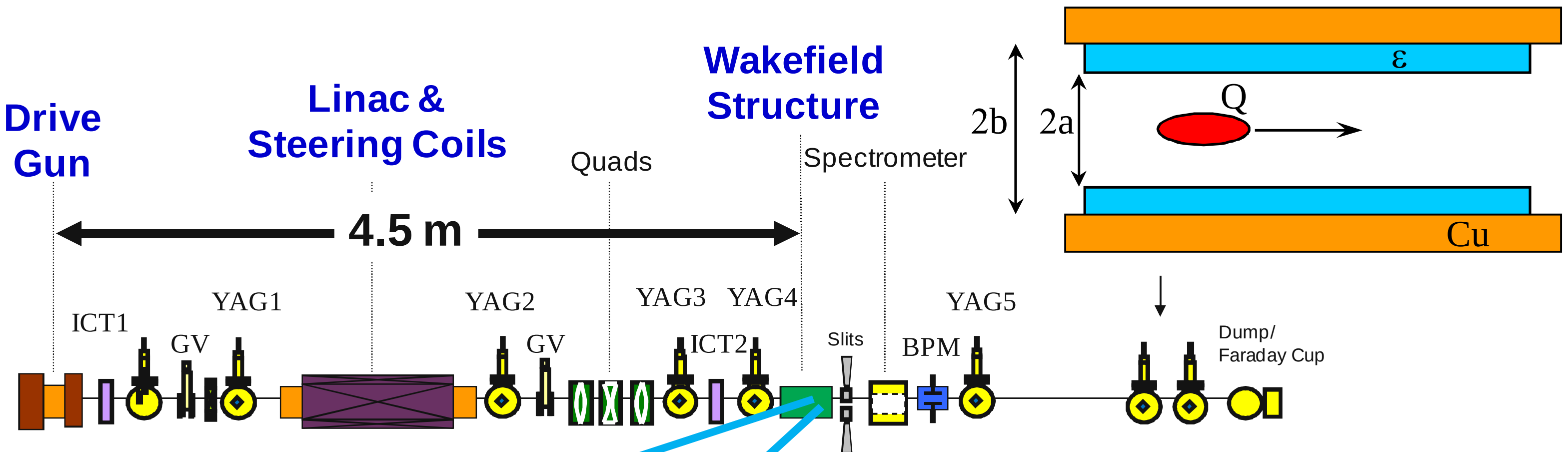
ICFA Workshop on Novel Concepts
for Linear Accelerators and Colliders.
SLAC, July 7-10 2009

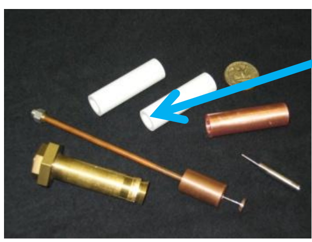
Motivation/Outline

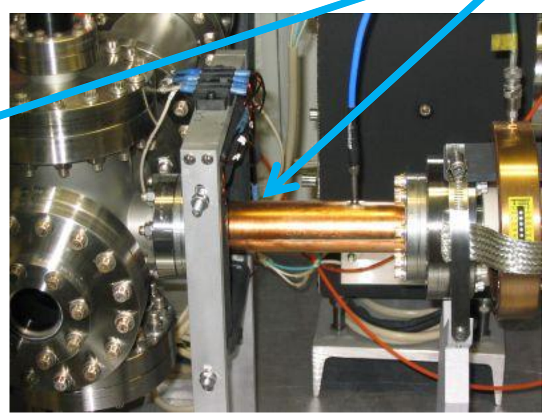
MW DLA issues: high gradient – drive beam, power extraction, tuning, efficiency, BBU, multipacting, ...

- High Gradient DLA
- 26 GHz Wakefield Power Extractor
- Tunable Dielectric Based Accelerator : Idea and Experiment
- Ferroelectric Based Fast High Power Switching
- Transformer Ratio X-Band Experiment, R>2 Demonstration
- Energy Modulation

Dielectric Based Accelerator







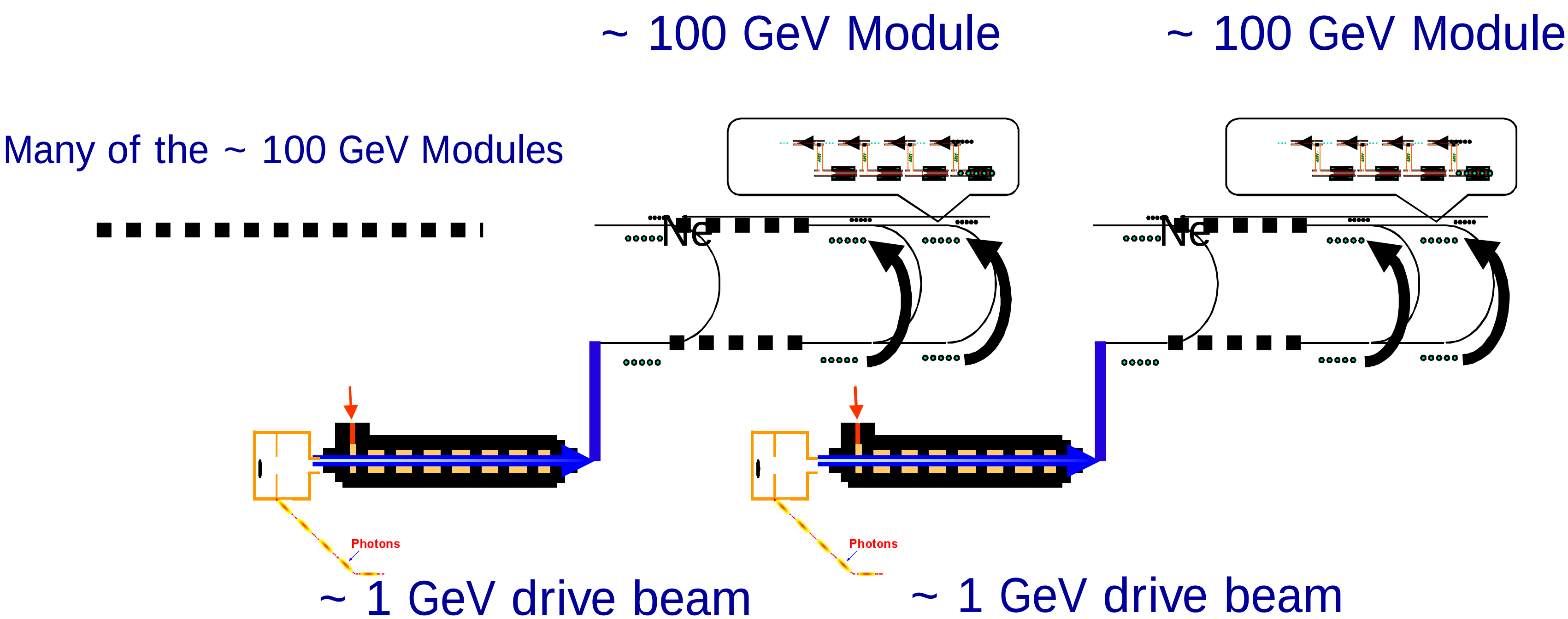
Single bunch operation

- Q=1-150 nC
- Energy=15 MeV
- High Current = 10 kAmp

Bunch train operation

64 bunches x 50 nC → 50 ns long

Dielectric Based Linear Collider Concepts



Major features: Short pulses (<20 ns), high gradient (200 ~ 300 MV/m)
Drive beam structure directly

Euclid Techlabs LLC

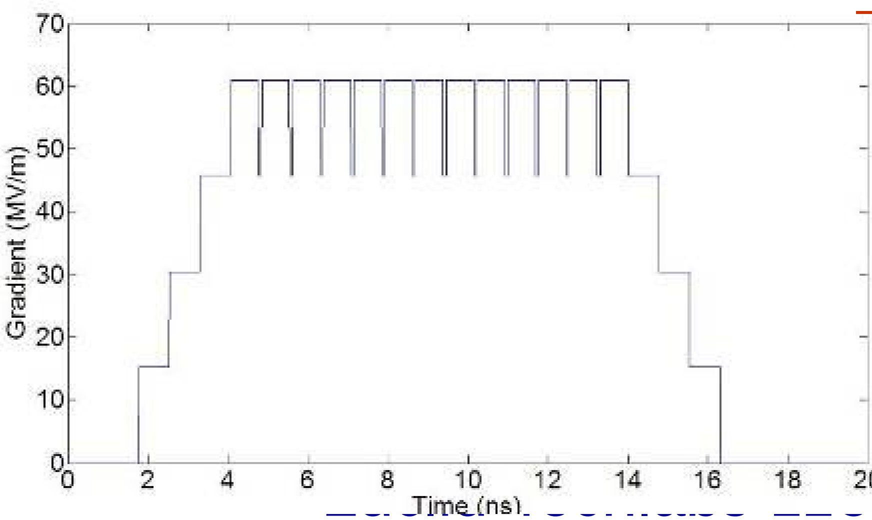
ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders. SLAC, July 7-10 2009

26GHz Dielectric-Based Power Extractor*

- A 26GHz power detector has been built and bench tested.
- A load has been built and bench tested.
- Beam test has been performed at AWA facility.

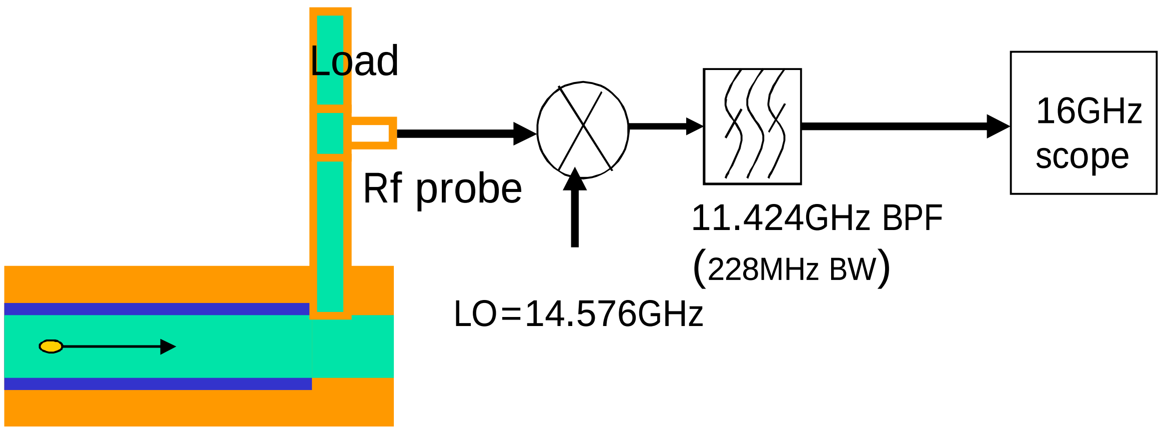
Parameters of 26GHz Dielectric Based RF Power Extractor

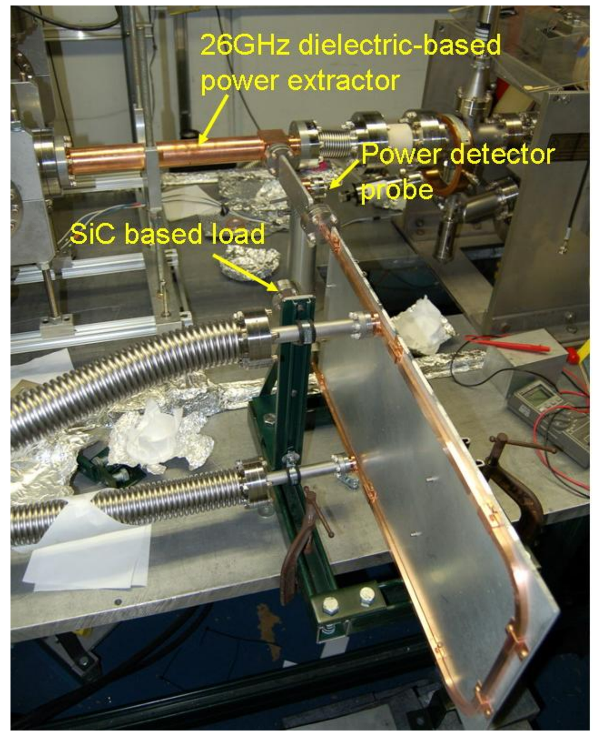
Geometric and accelerating parameters	value
ID / OD of dielectric tube	7 mm /9.068 mm
Dielectric constant	6.64
Length of dielectric tubes	300 mm
R/Q	9788 Ω/m
Drain time Td	3 ns
Steady power from AWA bunch train (20nC/bunch)	148 MW



ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders. SLAC, July 7-10 2009

Beam Test of the 26GHz Power Extractor @ AWA Facility (May~June, 2009)

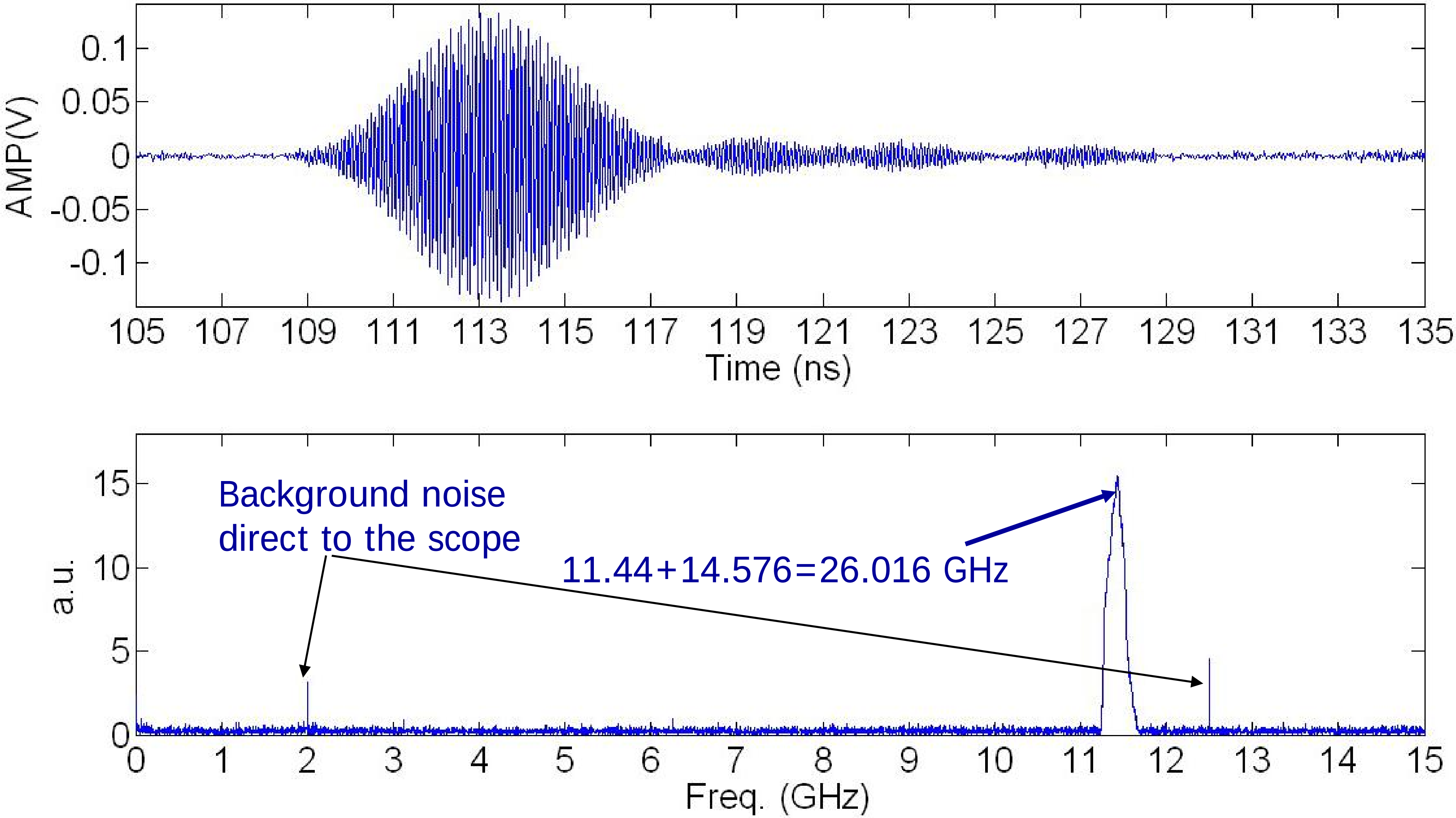




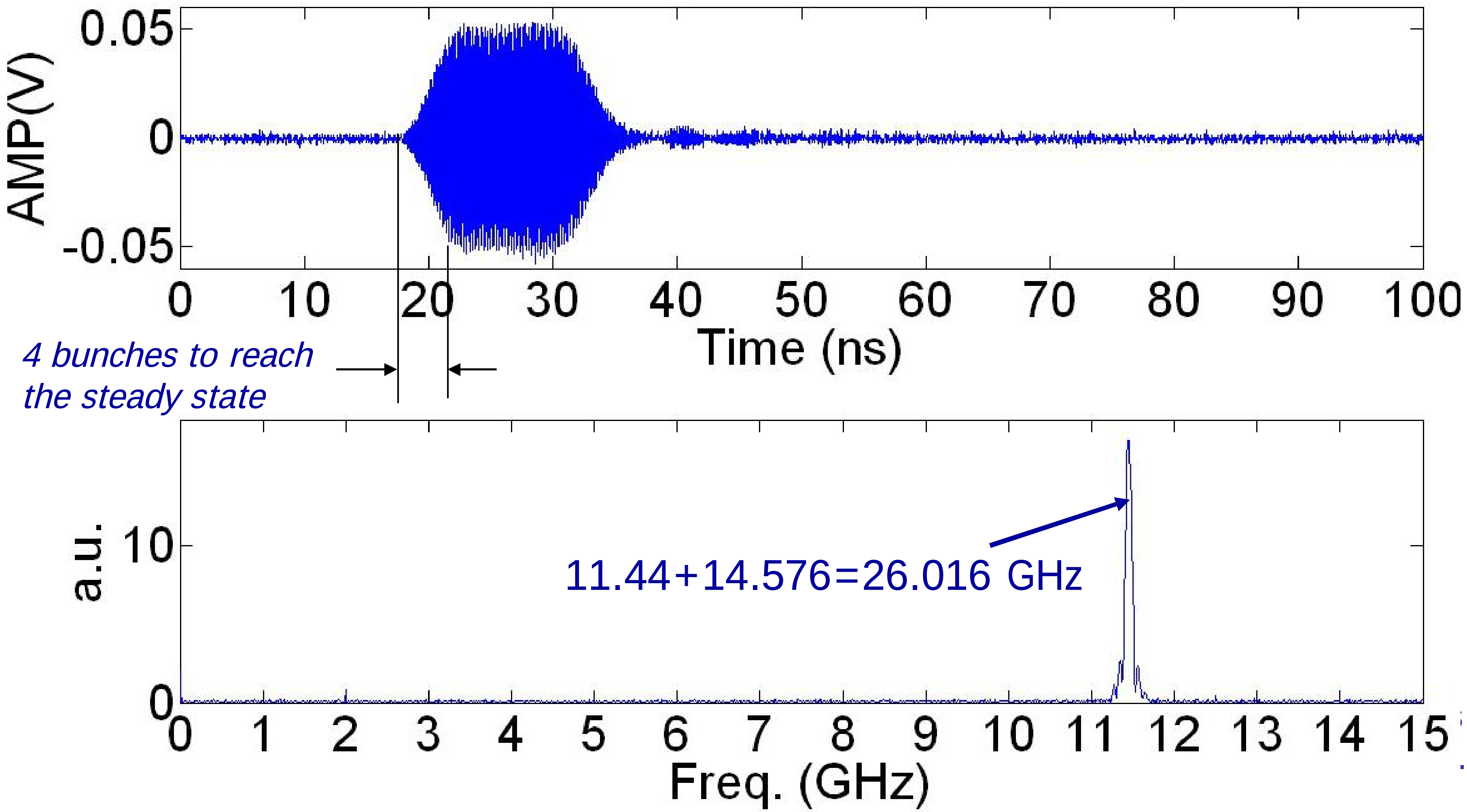
Performed 3 experiments to date:

- Single beam--- to check the frequency
- 16-Bunch train--- to check the rf pulse formation
- 4-bunch train--- to achieve the high rf power

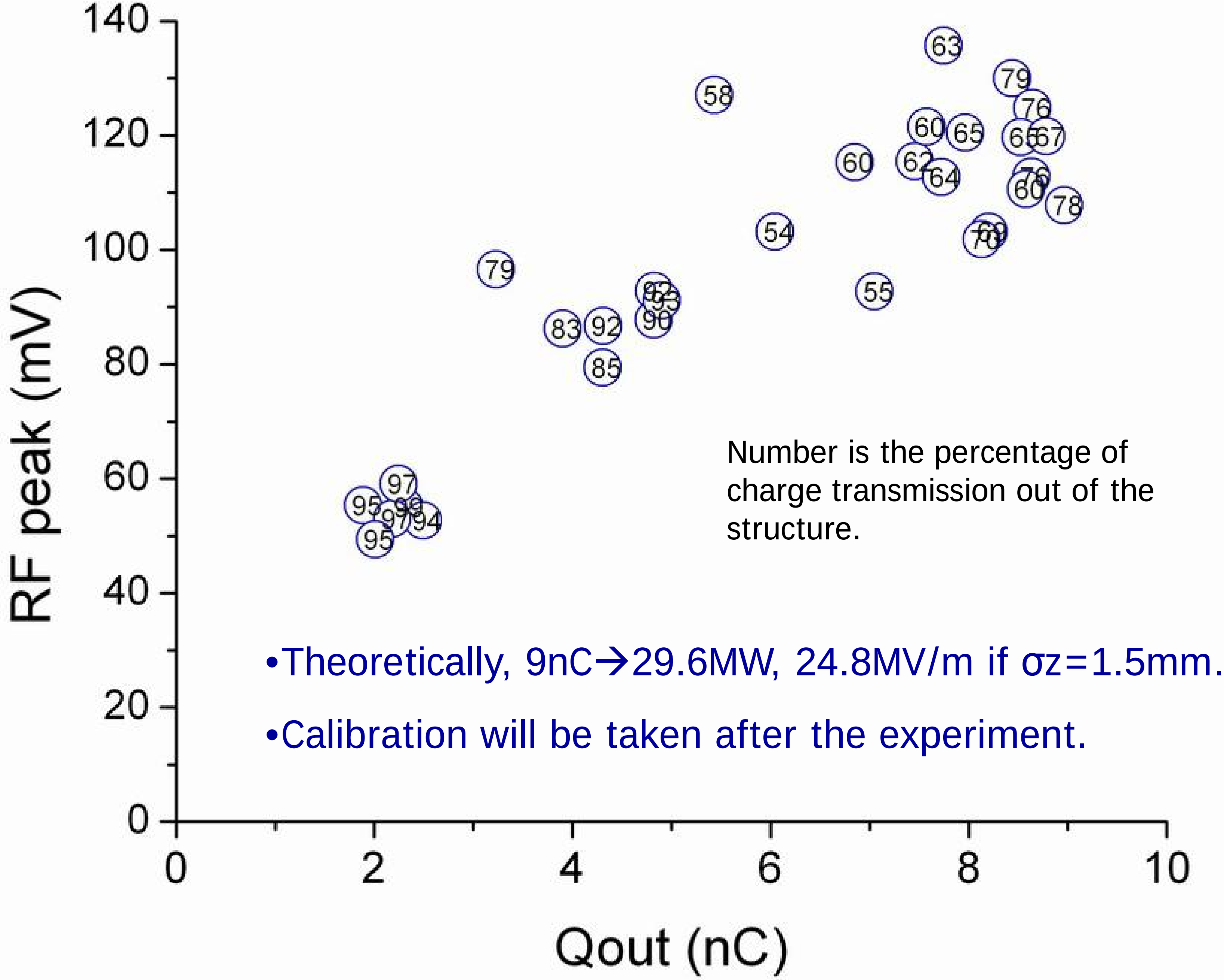
Down-converted rf Trace of the 26GHz Power Extractor (4bunches)



Down-converted rf Trace of the 26GHz Power Extractor (16 bunches with 769ps separation)



Charge Sweeping



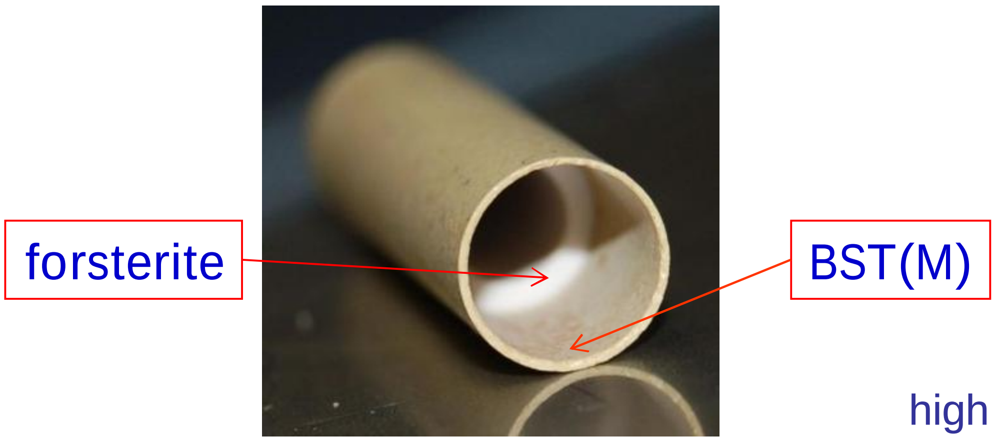
•Theoretically, 9nC→29.6MW, 24.8MV/m if σz=1.5mm.

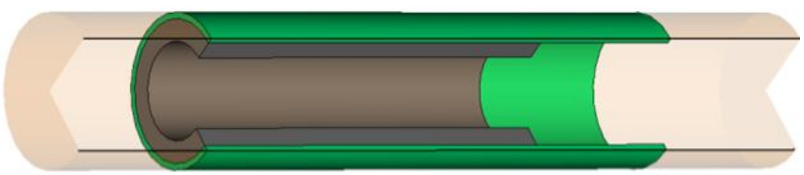
•Calibration will be taken after the experiment.

Summary for 26GHz Dielectric Based Power Extractor

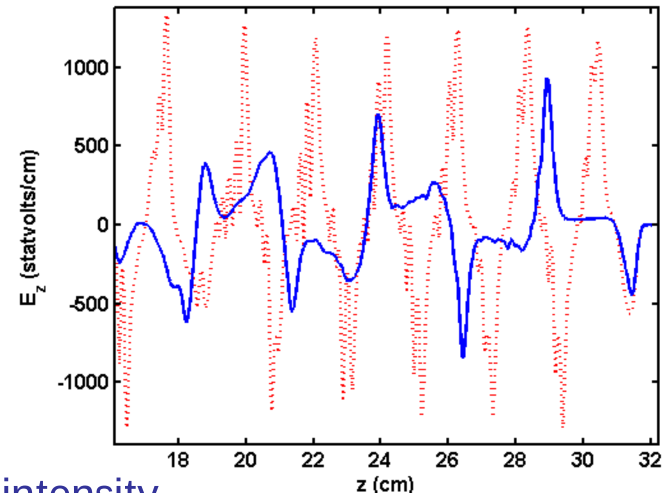
- Successfully demonstrated the high frequency, high power rf source using dielectric-based scheme.
- Experiment will be continued in the upgraded AWA facility next year.
- Design of a fully featured power extractor(with transverse modes damping) is needed to prevent BBU in the high charge transportation.

Tuning/Nonlinear Effects in Dielectric-Based Accelerator

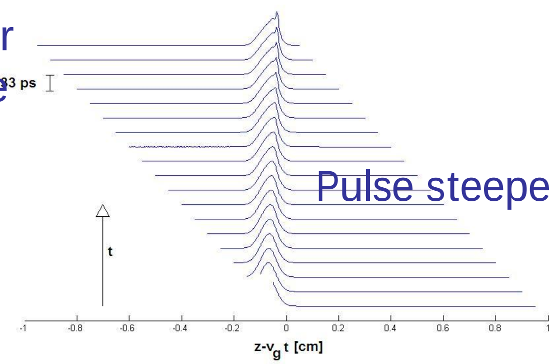




ε(E) for ferroelectric dielectric composite



high intensity wakefields in nonlinear structure



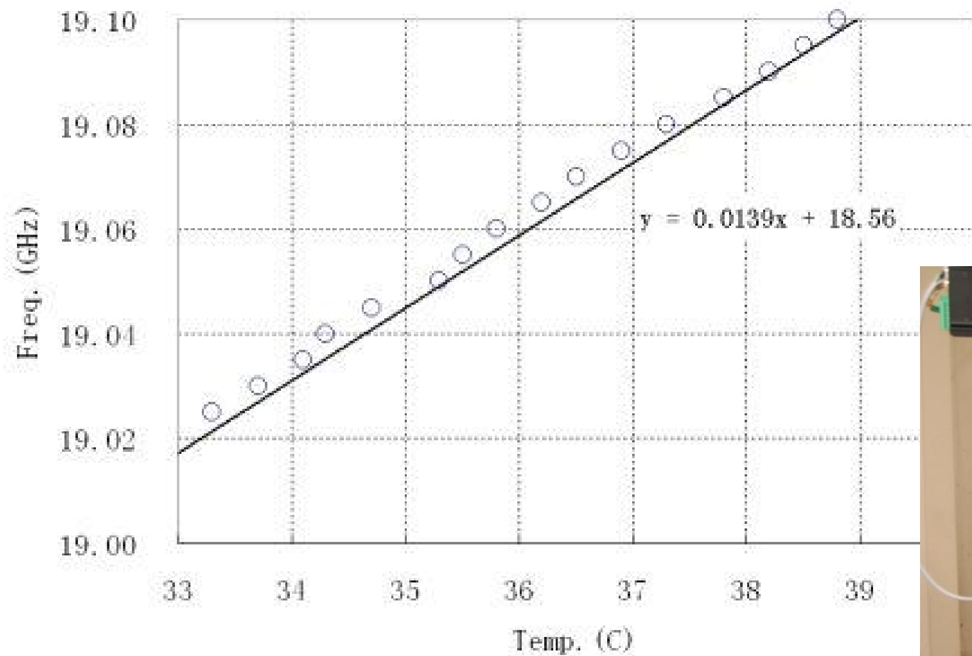
Pulse steepening

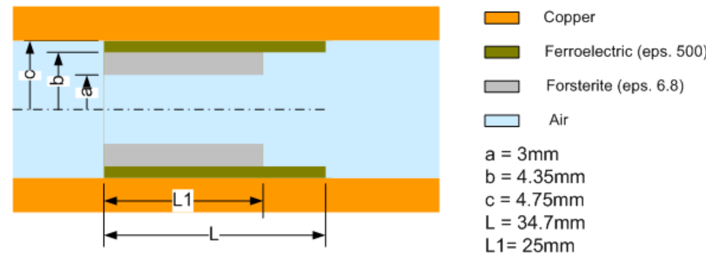
Euclid Techlabs LLC

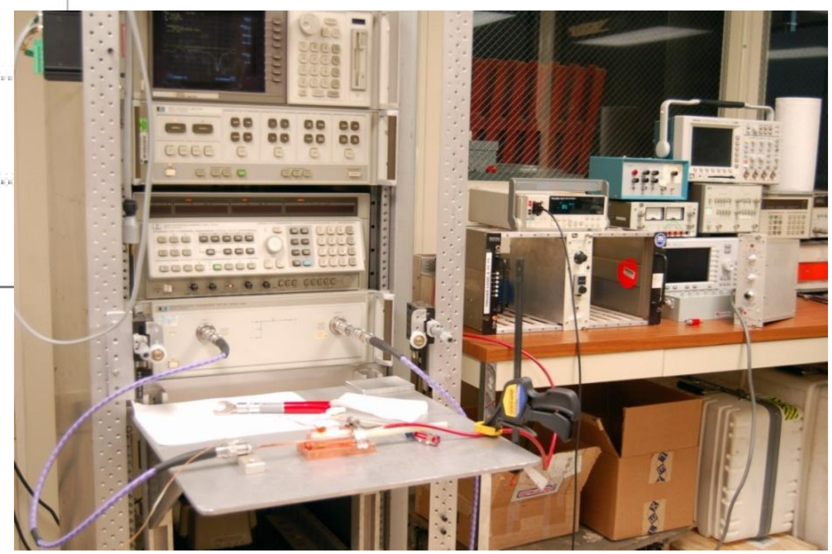
ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders. SLAC, July 7-10 2009

Tunable DLA

Temperature Tuning*







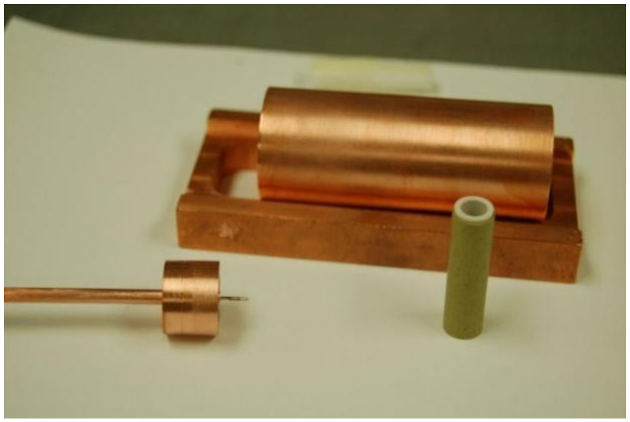
Temperature tuning of 14 MHz/^{0}K

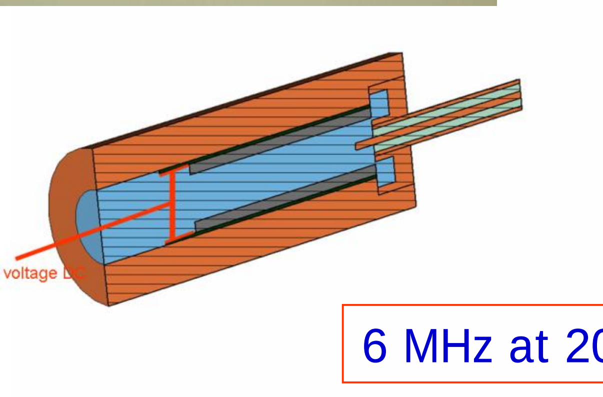
Euclid Techlabs LLC

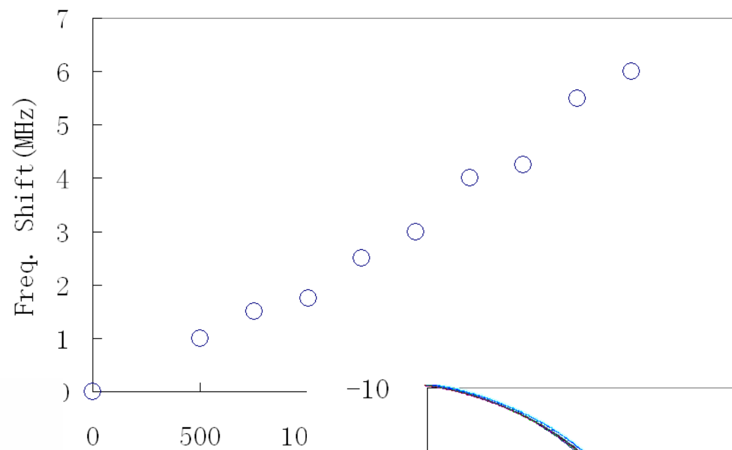
ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders. SLAC, July 7-10 2009

Tunable DLA

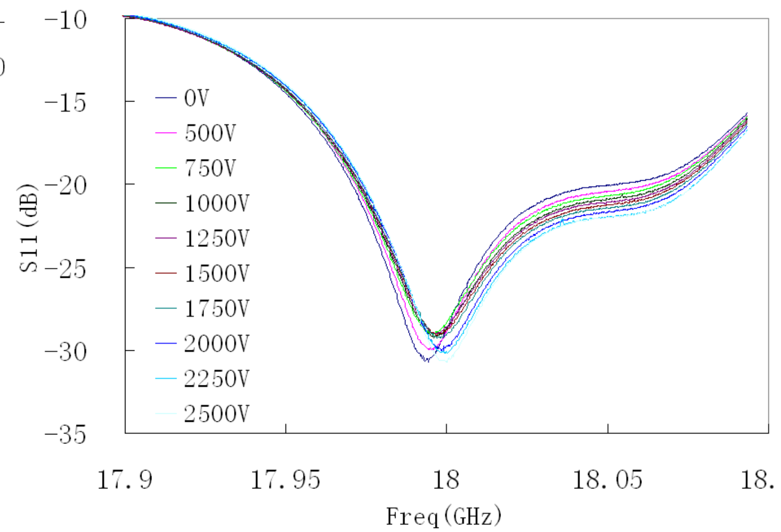
Fast DC Voltage Tuning







6 MHz at 20 kV/cm



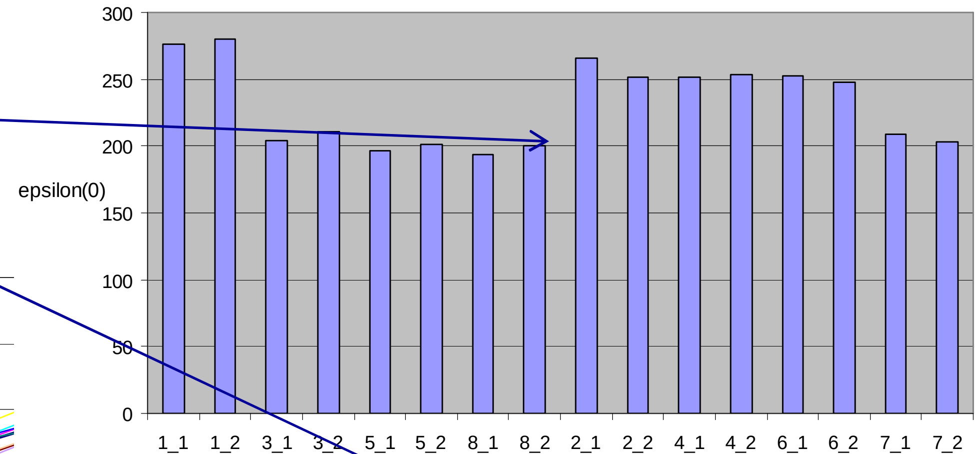
Euclid Techlabs LLC

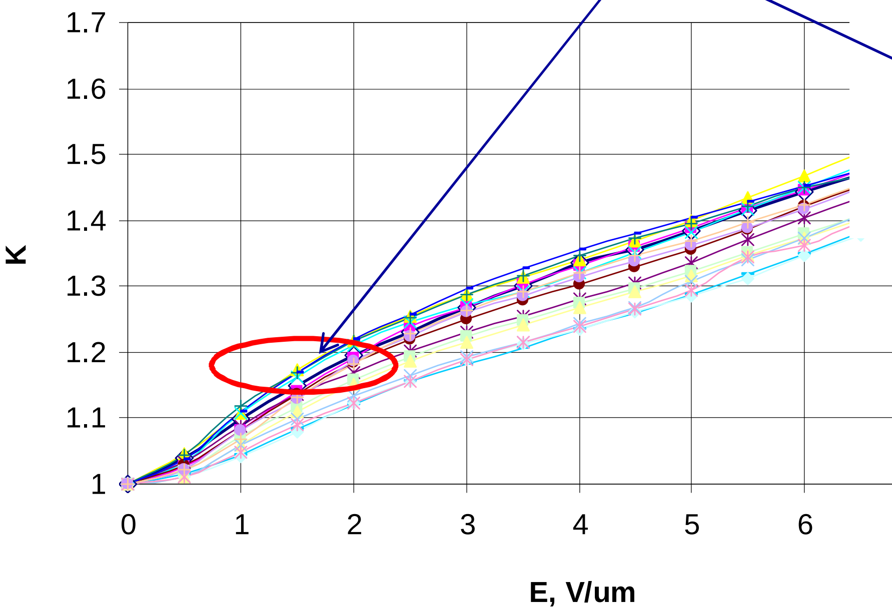
ICFA Workshop on Novel Concepts
for Linear Accelerators and Colliders.
SLAC, July 7-10 2009

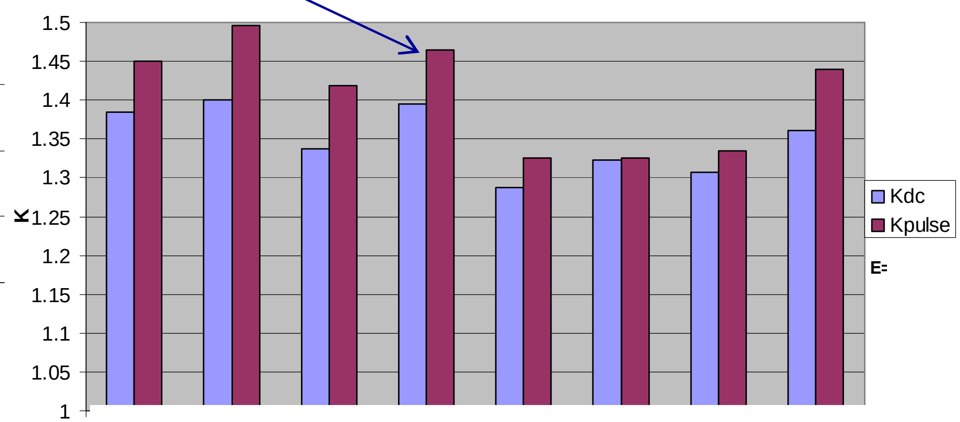
New Ferroelectric

ε< 300, k> 10% in air

Lower dielectric constant, higher tuning range



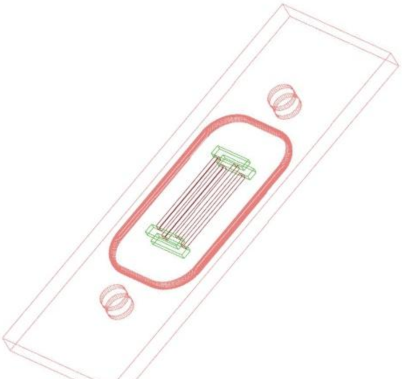


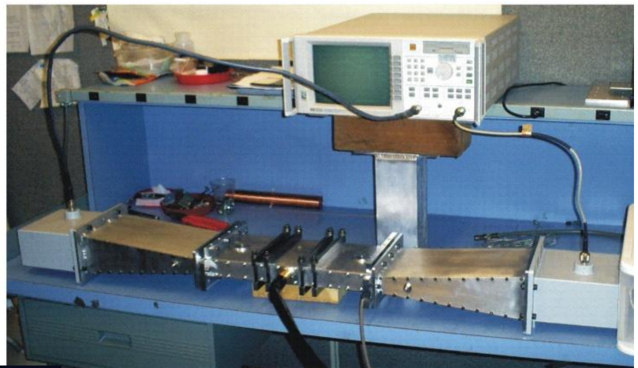


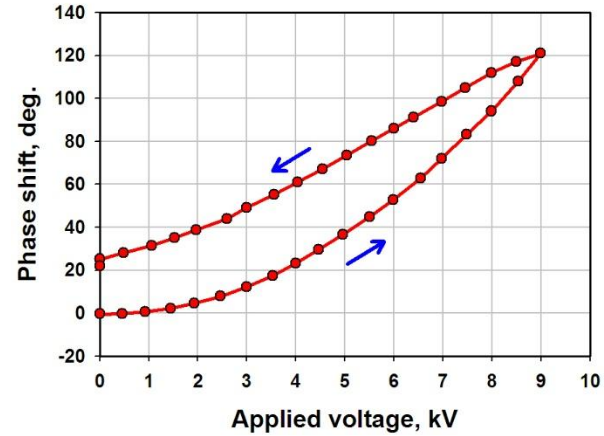
Euclid Techlabs LLC

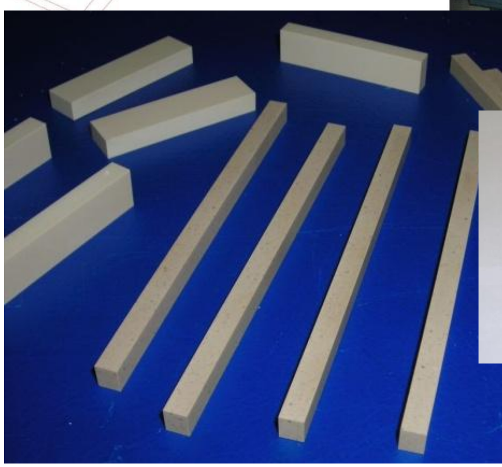
BST(M) Ferroelectric Based L-band High Power Tuner

Collaboration with Omega-P and FNAL

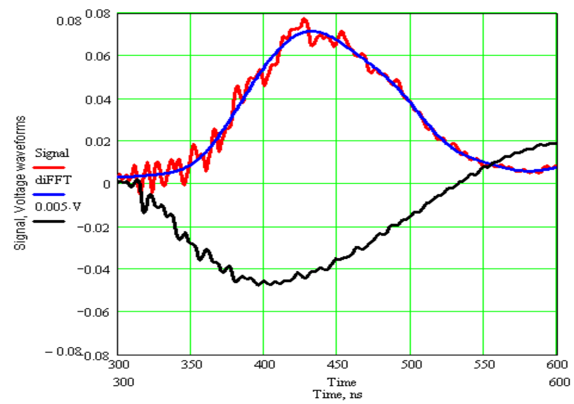








(b)



30 ns switching speed

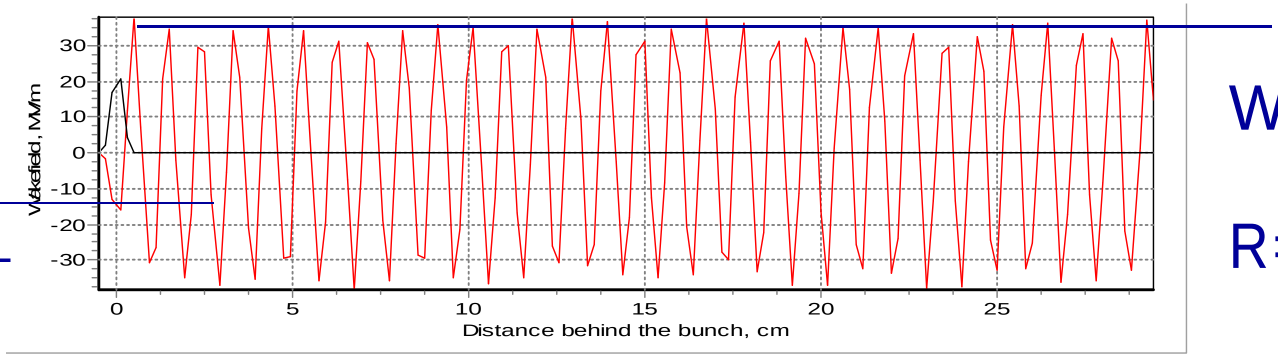
Euclid Techlabs LLC

ICFA Workshop on Novel Concepts for Linear Accelerators and Colliders.
SLAC, July 7-10 2009

Transformer Ratio

Transformer Ratio

R = (Max. energy gain behind the bunch) / (Max. energy loss inside the bunch).



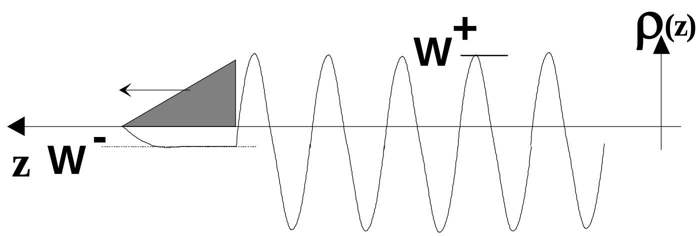
W^+

W^-

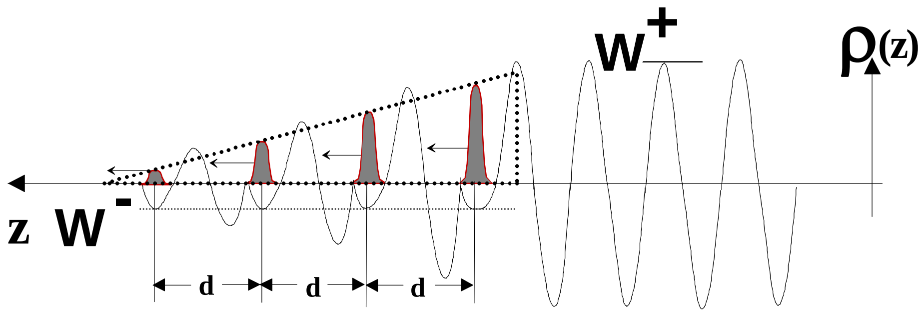
$R = W^+ / W^-$

R < 2 under very general conditions: linear media; a relativistic, longitudinally symmetric drive bunch; and identical paths through the system of both drive and witness beams.

Ramped Bunch Train



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



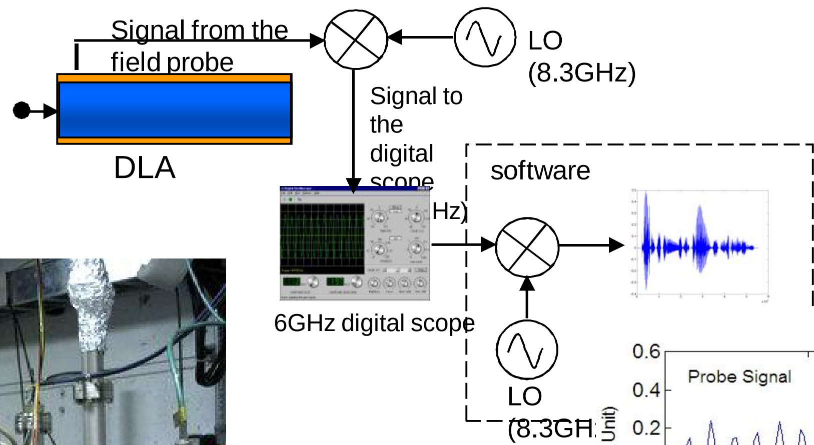
Reference: Schutt et. al., Nor Ambred, Armenia, (1989)

Some of the methods that can be employed *to obtain R>2* include*: a triangular drive bunch* longitudinal profile; a train of Gaussian drive bunches of progressively increasing charge (ramped bunch train, RBT); the ring type driver, use of a proton drive beam so that the particles within the bunch can change positions during deceleration; and nonlinear plasma dynamics.

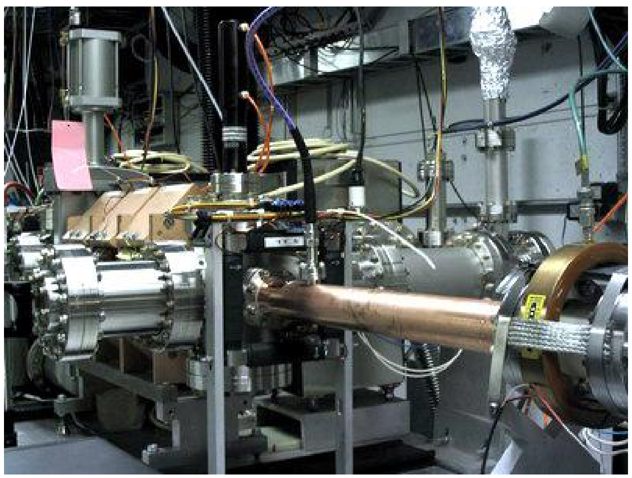
A single drive bunch was replaced by two bunches with charge ratio of 1:2:5 and a separation of 10.5 wavelengths of the fundamental mode

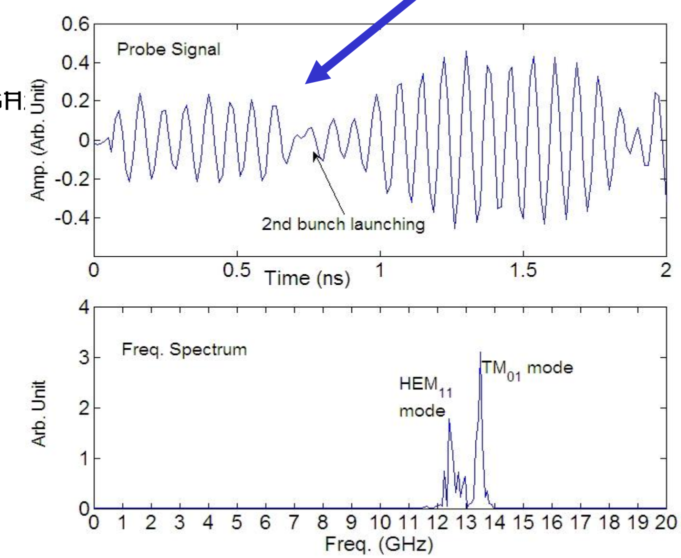
Transformer Ratio Experiment

two-bunch wakefield experiment setup



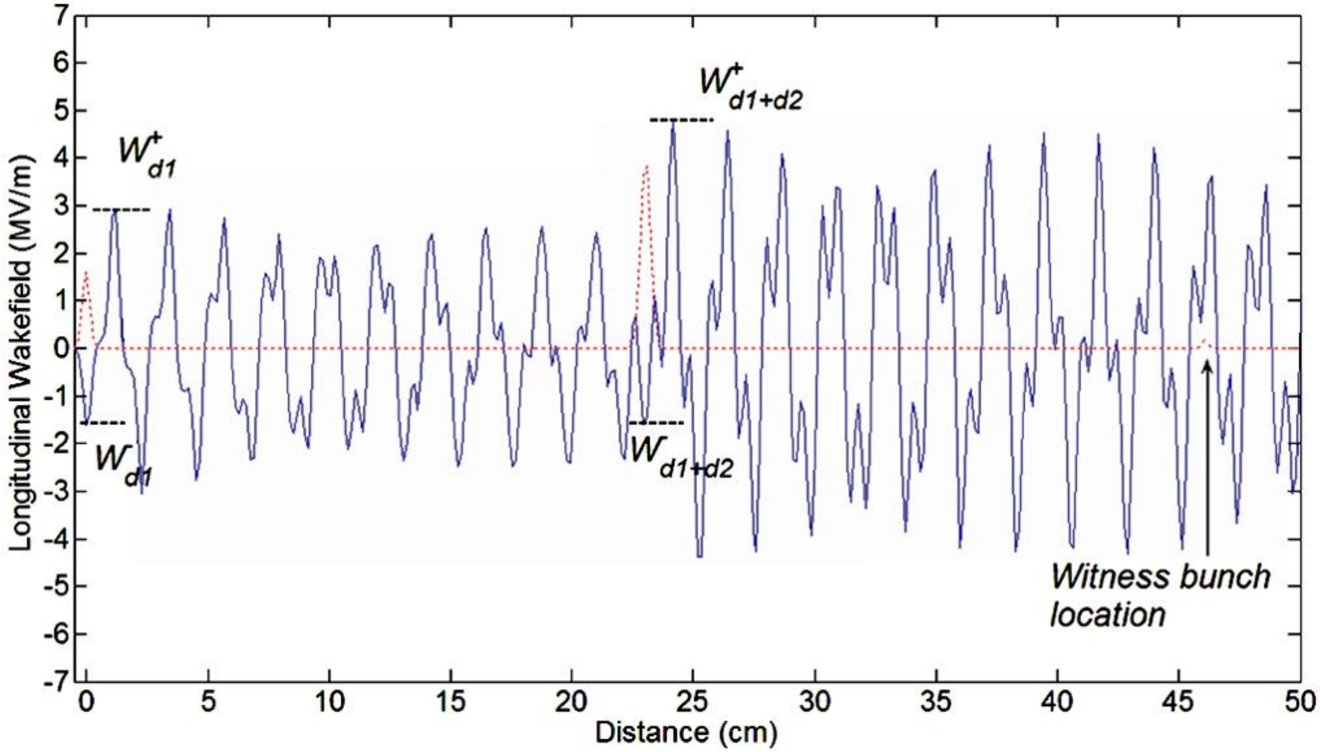
The field probe signal from the RBT in the 13.625 GHz DLA





Wakefields measurements

Leading and Tailing
8 nC and 20 nC bunches

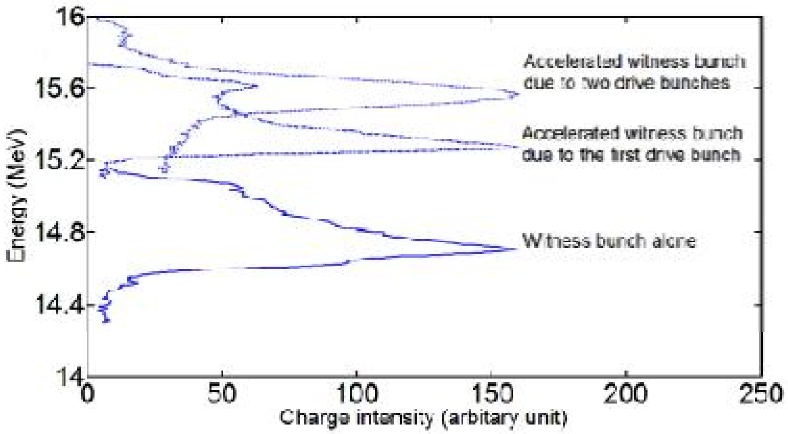


the transformer ratio increases correspondingly, from R~ 1.8 to R~ 3.

satisfying the requirement of an equal decelerating field inside each bunch

R>2 Experimentally Demonstrated.

C.Jing, A.Kanareykin, J.G.Power et al. PRL 98, 144801, 2007

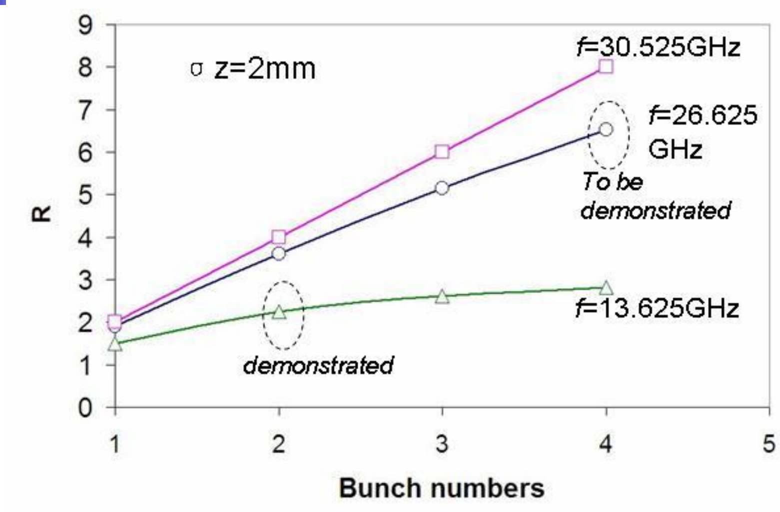


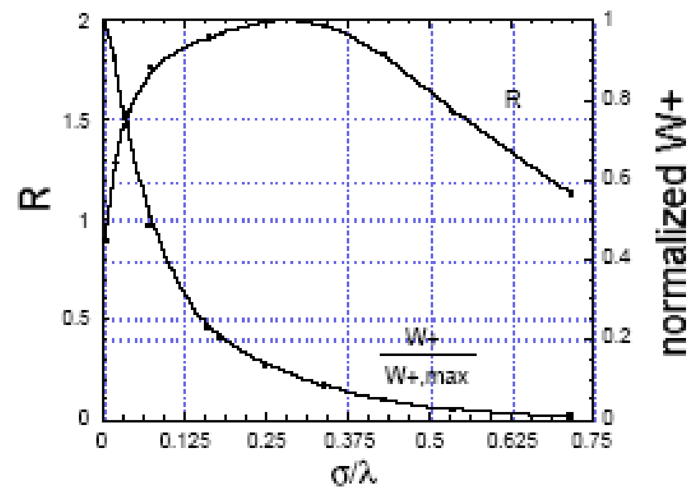
Enhancement Factor of 1.31

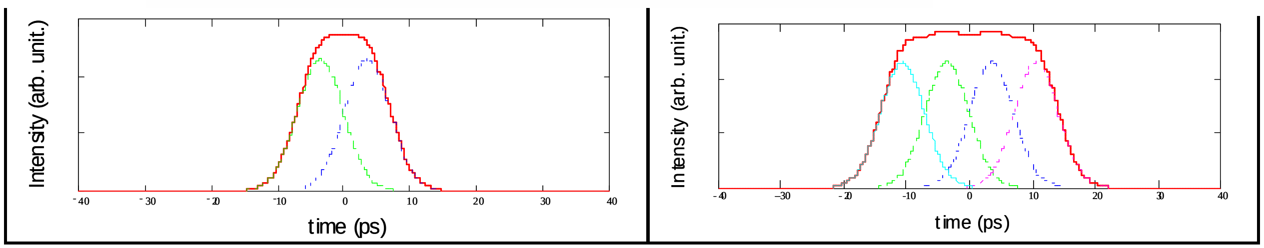
Transformer Ratio R~2.3

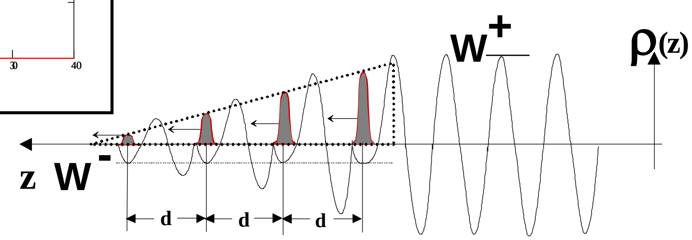
An average measured transformer ratio enhancement by a factor of 1.31 over the single drive bunch case was obtained, R>2 has been demonstrated.

4 bunch Transformer Ratio Experiments



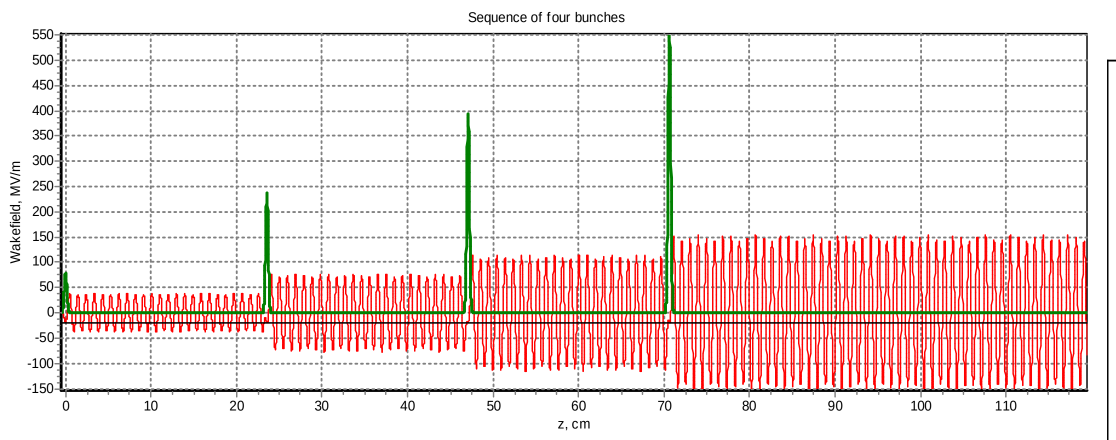


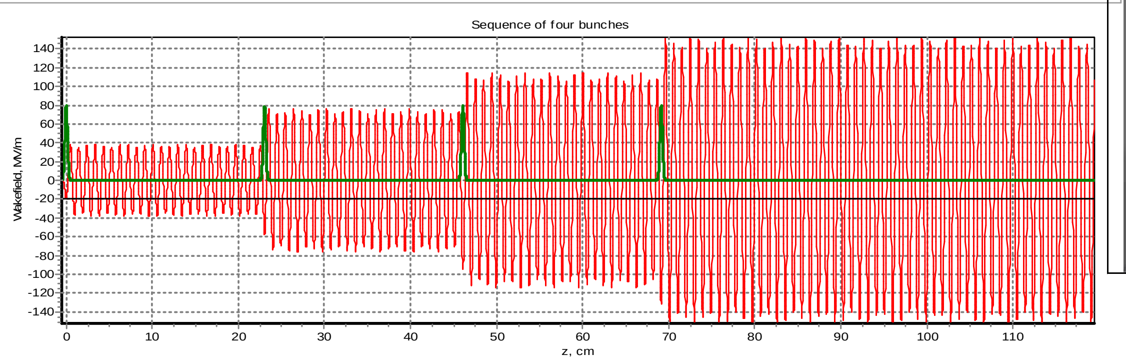




laser pulse stacking method to stretch the AWA laser pulse from FWHM = 8 ps to 26.5 ps.

Energy Modulated Bunch Train





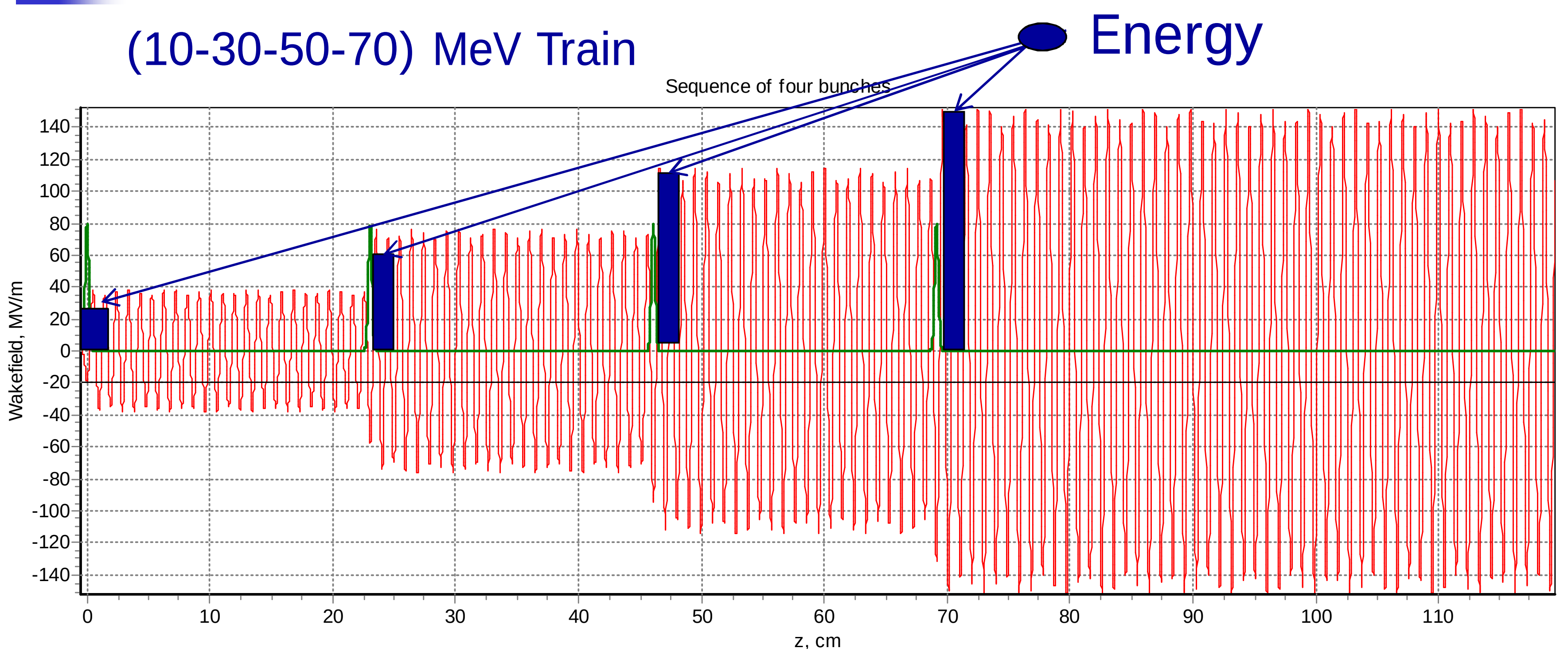
Radius of channel (Rc,cm)	0,15	Radius of channel (Rc,cm)	0,15
Radius of dielectric (Rd,cm)	0,247	Radius of dielectric (Rd,cm)	0,247
Radius of ferroelectric (Rw,cm)	0,262	Radius of ferroelectric (Rw,cm)	0,262
Permittivity of dielectric	5,7	Permittivity of dielectric	5,7
Permittivity of ferroelectric	5,7	Permittivity of ferroelectric	5,7
Number of bunches	4	Number of bunches	4
Number of modes	5	Number of modes	5
Bunch length (sigmaz, cm)	0,15	Bunch length (sigmaz, cm)	0,15
Distance between 1 and 2 (cm)	23,55	Distance between 1 and 2 (cm)	23,04
Distance between 1 and 3 (cm)	47,09	Distance between 1 and 3 (cm)	46,09
Distance between 1 and 4 (cm)	70,63	Distance between 1 and 4 (cm)	69,14
Charge of 1 bunch (nC)	20	Charge of 1 bunch (nC)	20
Charge of 2 bunch (nC)	60	Charge of 2 bunch (nC)	20
Charge of 3 bunch (nC)	100	Charge of 3 bunch (nC)	20
Charge of 4 bunch (nC)	140	Charge of 4 bunch (nC)	20
Base frequency	31,21 GHz	Base frequency	31,21 GHz
Transformer ratio	7,293	Transformer ratio	1,159
Maximal wakefield	153,7 MV/m	Maximal wakefield	152,3 MV/m

A.Kanareykin et al, in preparation

For the same gradient: Ramped – 220 nC; Flat – 80 nC

Energy Modulated Bunch Train. Energy Distribution

(10-30-50-70) MeV Train



Charge distribution is 20-20-20-20 nC, 1.5 mm length AWA bunch generated at the diamond based DLA structure with the inner radios of 1.5 mm, outer radius of 2.62 mm, ID=3 mm, OD= 5.24. Spacing between the bunches corresponds to 1.3 GHz or ~ 23 cm. Maximal accelerating gradient behind the train is 150 MV/m.

A.Kanareykin et al, in preparation

Energy Modulation: pros and cons

Ramped Bunch Train

Pros:
- laser beam manipulation for the train profile generation

Cons:
- lower accelerating gradient
- high charge for the last bunches
- transverse fields increase
- focusing for ramped bunch charges

A.Kanareykin et al, in preparation

Energy Modulated Bunch Train

Pros:
- higher accelerating gradient
- flat and low charge bunch train
- last bunches have higher energy
- transverse stability

Cons:
- energy modulated driver bunch train generation
- focusing of the energy profiled bunch train

SUMMARY

1. Successfully demonstrated the 26GHz, high power rf source using dielectric-based scheme.
2. Design of a fully featured power extractor (with transverse modes damping) is needed to prevent BBU in the high charge transportation.
3. Tunable dielectric based accelerator concepts is presented
4. Transformer ratio experiment demonstrated R>2 for DWA
5. Energy modulated beam is considered, pros and cons are discussed.