Recent Developments And Progress Towards EM Structures Based Accelerators

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Outline of talk

- Why EM Structures?
- Species of accelerators based on EM structures
- Common Issues
- Development of scalable technologies
  - Experiments and test stands
  - 1 GeV module strawmen
- Summary

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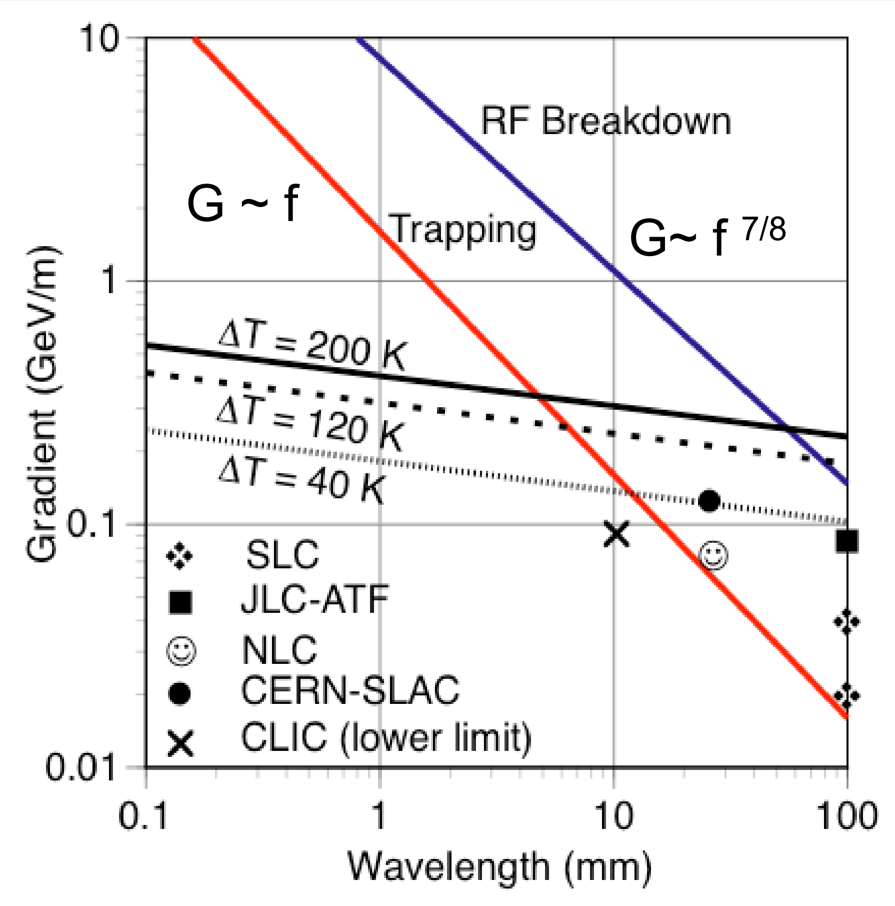
Why EM Structures?

Standard Copper Structures Have Serious Limitations



Dark-current trapping and material failure considerations lead to the conclusion:

Higher gradient means higher frequencies.

Structures are devices that allow to control the interaction (usually inaccessible) by proper design of the boundaries (accessible).

We can efficiently generate large amplitude EM fields over large ranges in wavelength - rf, mm, THz, IR, optical.

We can build structures that support and guide EM fields to provide acceleration over finite distances.

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Species of EM Structure Based Accelerators

- 'Slow-wave', synchronous, E || v
  - DWA — Dielectric Wakefield Accelerators
  - PBGA — Photonic Band-Gap Accelerators
- 'Fast-wave', quasi-synchronous, E ⊥ v
  - IFEL — Inverse Free Electron Lasers
  - VLA — Vacuum Laser Accelerators

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Common Issues

Material properties, power handling limits achievable gradient

Rf - mm structures

- Beam impact
- Explosive field emission
- Ion bombardment
- Multipactoring
- Arc discharge
- Pulsed heating fatigue

Optical structures

– Thermal ablation (t > ~ 10ps)

– Multiphoton ionization (t < ~ 10 ps)

– Short pulse (t << 10 ps) damage threshold is independent of pulse length

Transfer efficiency

Structure Mode and Impedance

Transformer Ratio Limits

Trapping Efficiency

Wakefields

Transverse wakes for slow-wave devices

Longitudinal wakes and energy spread for fast-wave devices

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Development of Scalable Technologies

Much current research is devoted to exploring techniques that may be extensible in frequency and accelerating gradient

- DWA
  - Tailored/ramped drive beam generation
  - Accelerating structures
  - Planar geometries
- PBGA
  - First rf structures
  - First W-band and optical structures
- IFEL
  - Successful trapping and acceleration at 10 μm
  - Extension to THz and optical frequencies
- VLA
  - Proof of principle experiments

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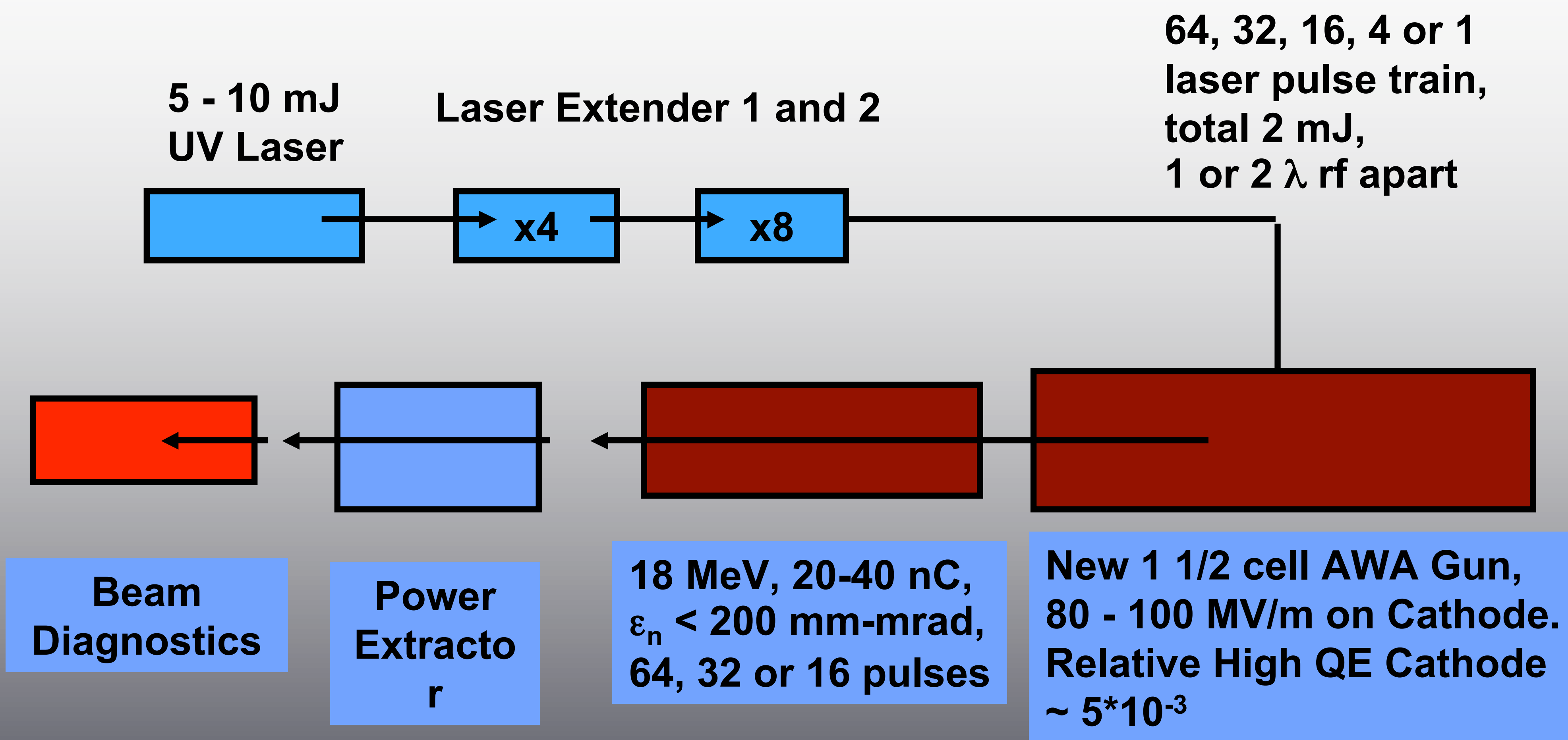
Drive Beam Generation Demonstration at ANL.



Current Goal: 100 MeV net gain

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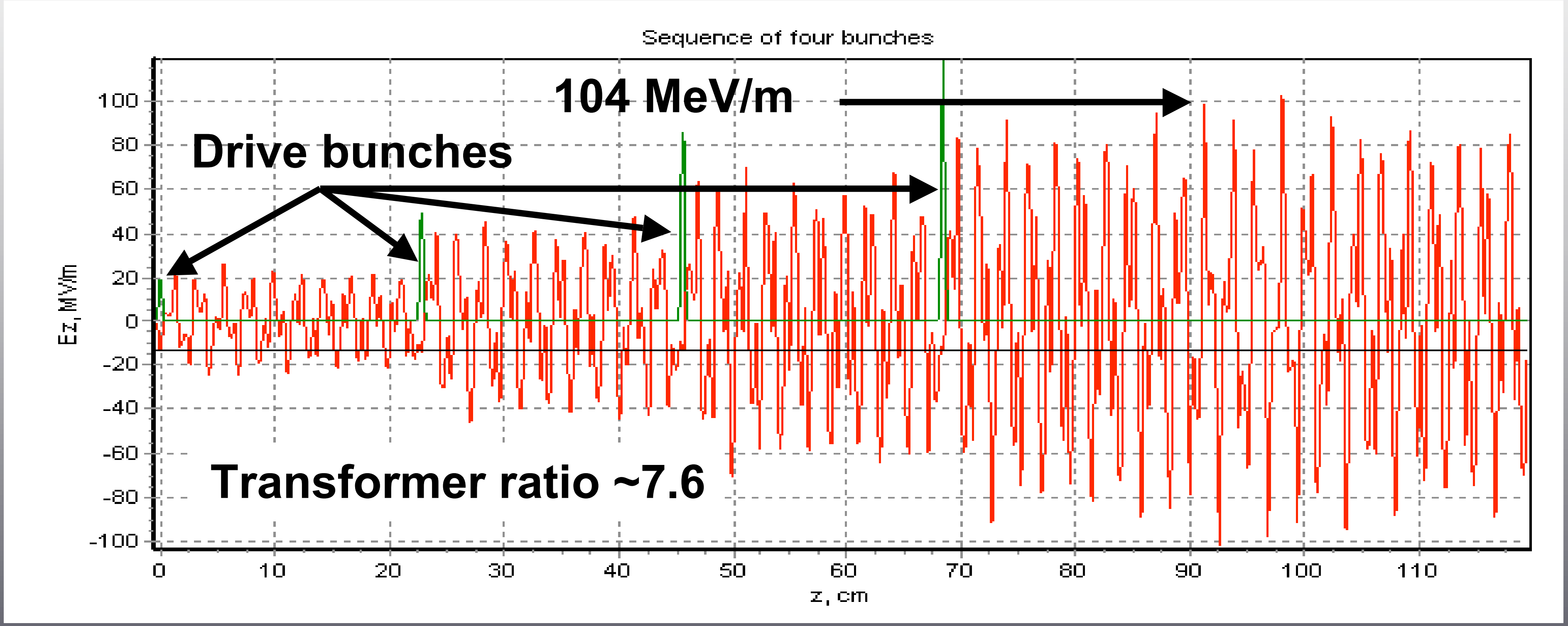
AWA Enhanced Transformer Ratio Experiment

Proof of principle experiment: 2-6-10-14 nC drive train
>100 MeV/m acceleration for (15-39-67-93) nC drive train



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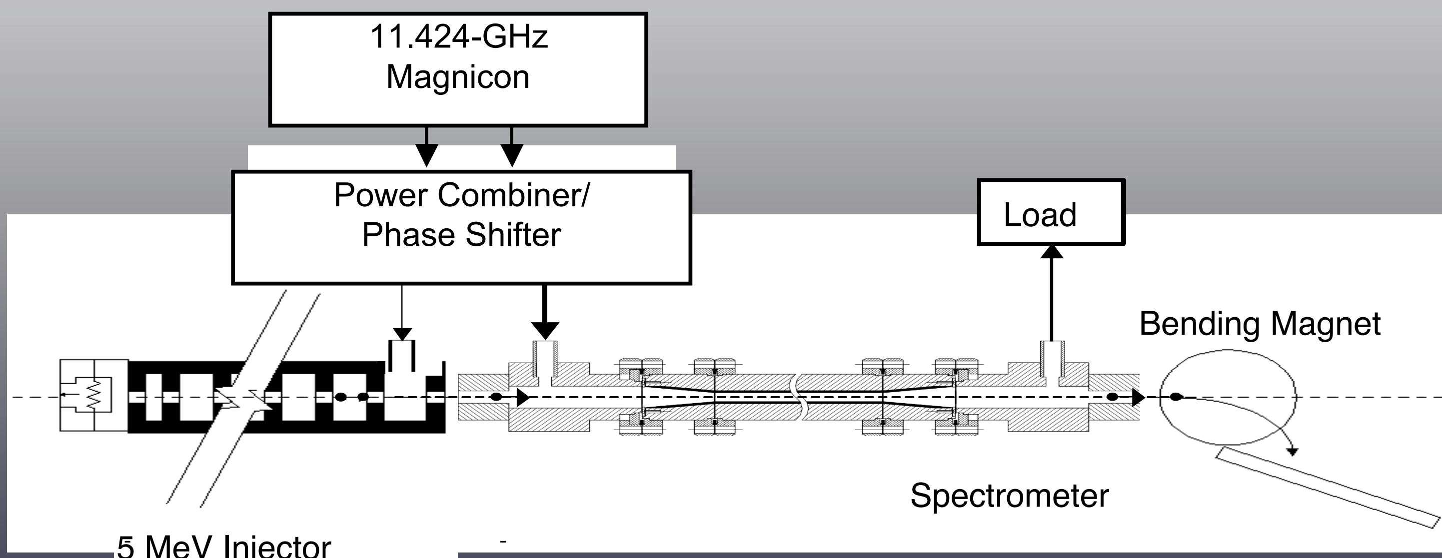
20-MeV Dielectric-Loaded Accelerator Test Facilty

- NRL X-band Magnicon Facility (Omega-P, Inc.)
- DLA Structure (0.5 m) Development (ANL)
- High Power Testing (ANL + NRL)
- X-band Technology – RF power distribution (SLAC)
- 5-MeV electron beam injector (Tsinghua University, Bejing)
- Ceramic brazing technology (RWBruce Associates, Inc. + NRL)
- Final Goal: Compact 20-MeV DL Test Accelerator



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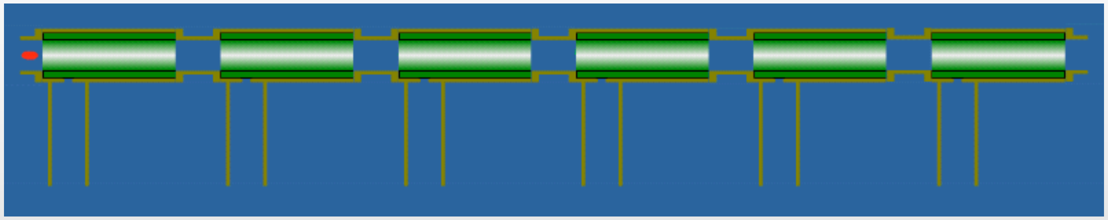
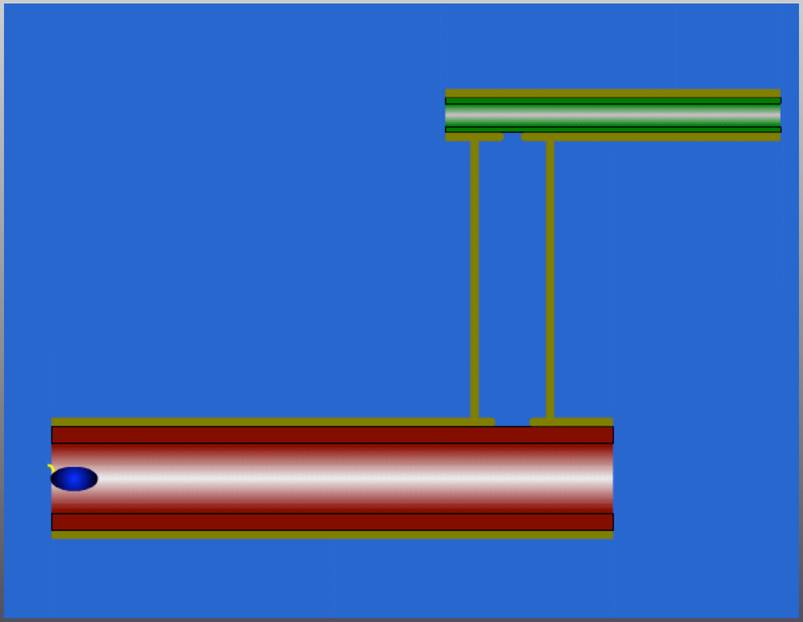
1-GeV Two-Beam Accelerator Module



Drive beam
- High power generation using a beam from RF photo-cathode gun and accelerator
- 20 A, 200 MeV, 20 ns (4 GW)
- Drive bunch train (~30 bunches)

Main (output) beam
- Energy gain = 1 GeV
- Charge = 1 nC
- RMS pulse length ~ 1 ps
- Acceleration does not disrupt emittance

Accelerator structure
- Operating frequency: 60 GHz
- Acceleration: 333 MV/m
- Power requirement: 500 MW
- Accelerator length: 3 meter
- RF pulse length: 6 x 16 ns



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Ongoing DWA Studies

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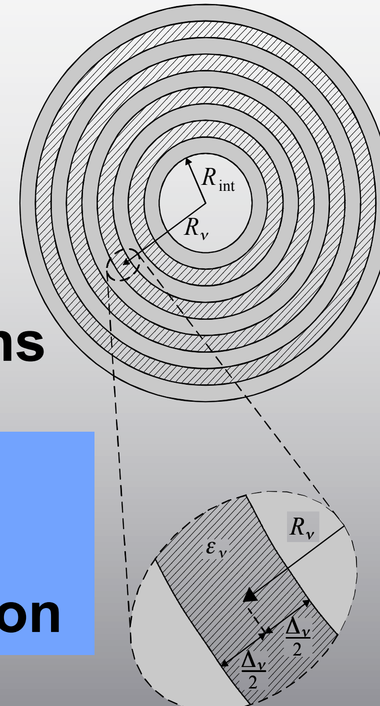
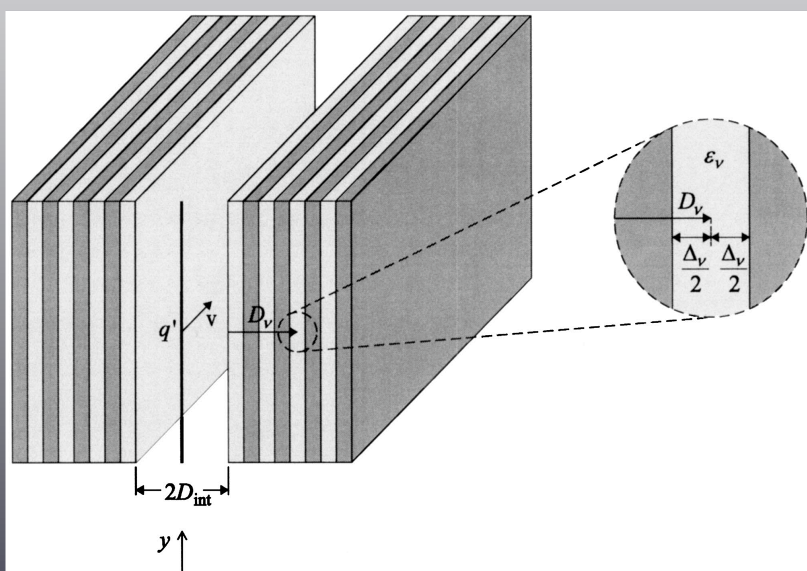
- **Multilayer dielectric loaded structures have improved transmission in fundamental mode.** ***Lower losses!***
- **Multilayers improve vacuum mode confinement**

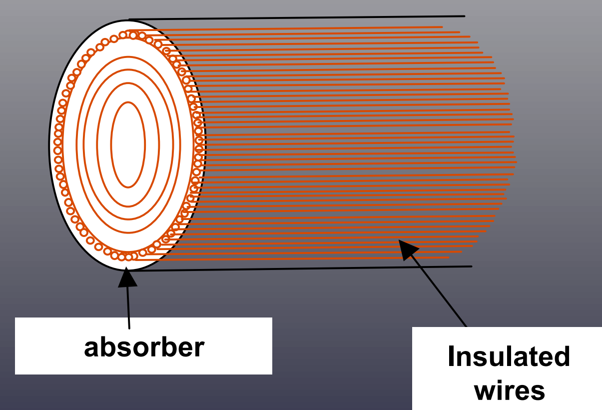
Greater transfer efficiency!

- **Inner-most layer : 'stub-tuner' to match modes in 2 regions**





Ferrite loaded DLAs provide BBU (Beam Breakup) HOM suppression



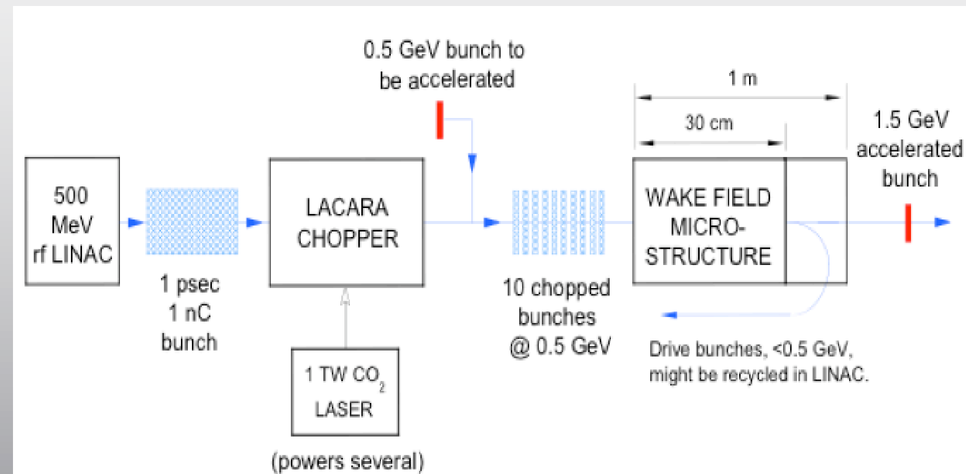
Advantages Of Planar Dielectric Structures

- Strong suppression of transverse wakefields
- Can be easy to build and tune
- Breakdown limitations may be less severe

Planar structure fed by optically bunched train (Columbia)

Wake field amplitudes to 1.1 GeV/m

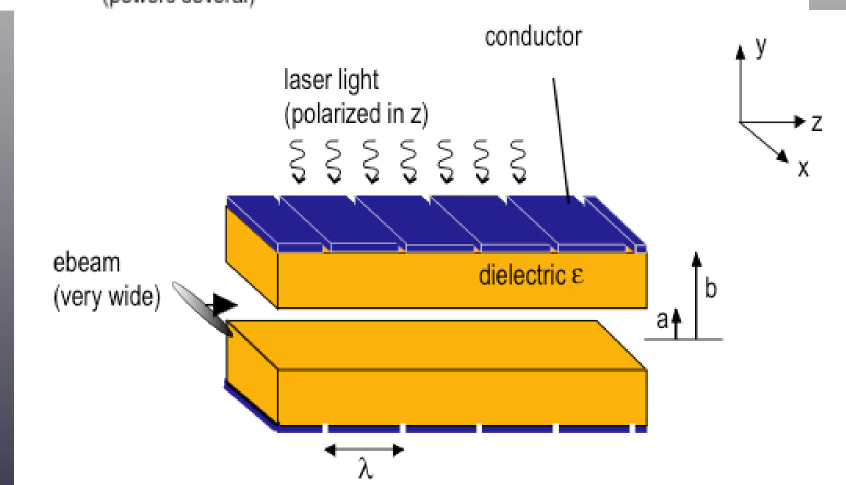
BBU studies: stability over 10's cm



Novel resonant dielectric structure excited with 340 μm THz radiation (UCLA)

Multi-layer structures for IR loading

~100 MeV/m from ~100 MW excitation



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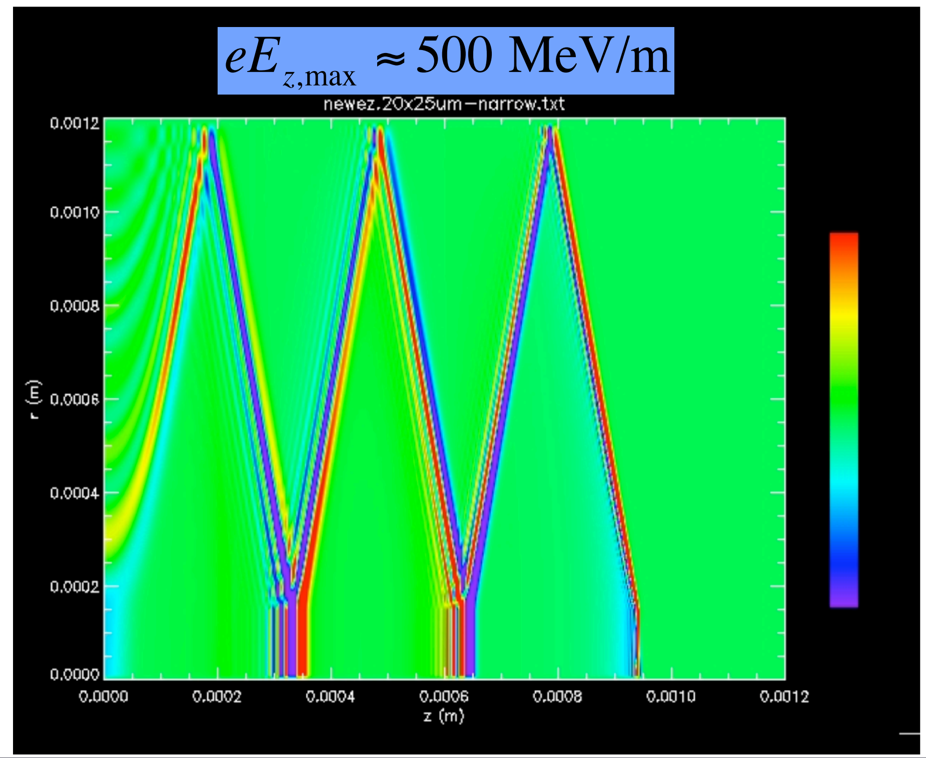
Cerenkov Wake Accelerator Experiment on E-163

Examine structure fabrication and field limits
Wavelength dependence, Beam Wake vs. Optical Excitation

Initially short (cm) tubes - 10's MeV
Production of coherent Cerenkov radiation
- **Spectrally resolve**

Breakdown studies
- **Optical emissions**
- **Plasma formation (electrical)**
- **Post-mortem**

Variation of tube parameters



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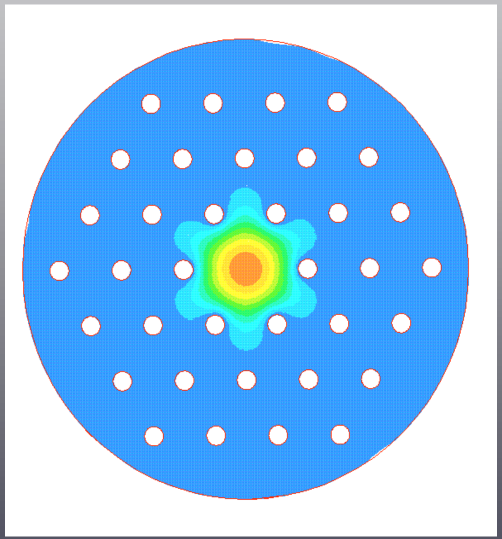
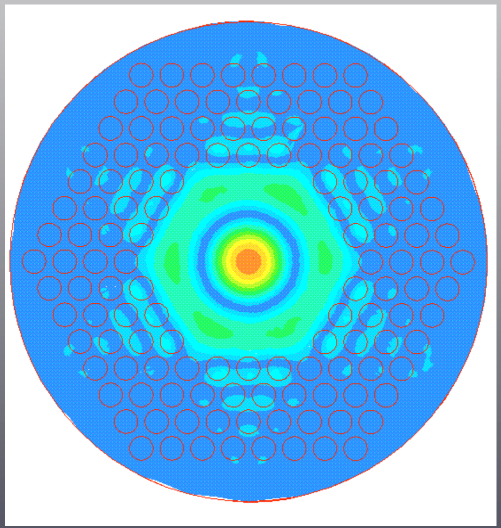
PBG resonators and waveguides

2D PBG structures are of main interest for accelerator applications.
If a wave cannot propagate through a photonic crystal, then a mode can form in a crystal defect.
We can construct a PBG resonator or PBG waveguide.

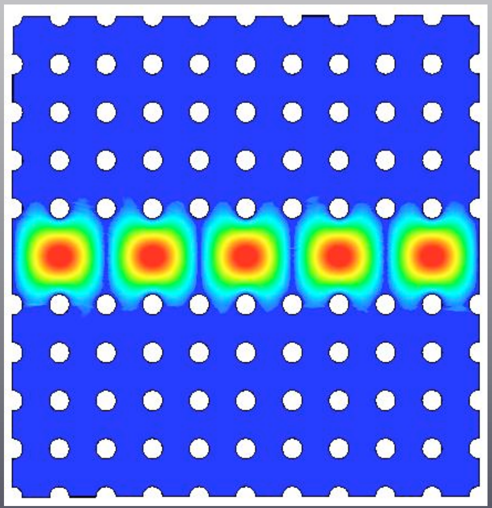
PBG resonator



Higher order mode PBG resonator



PBG waveguide



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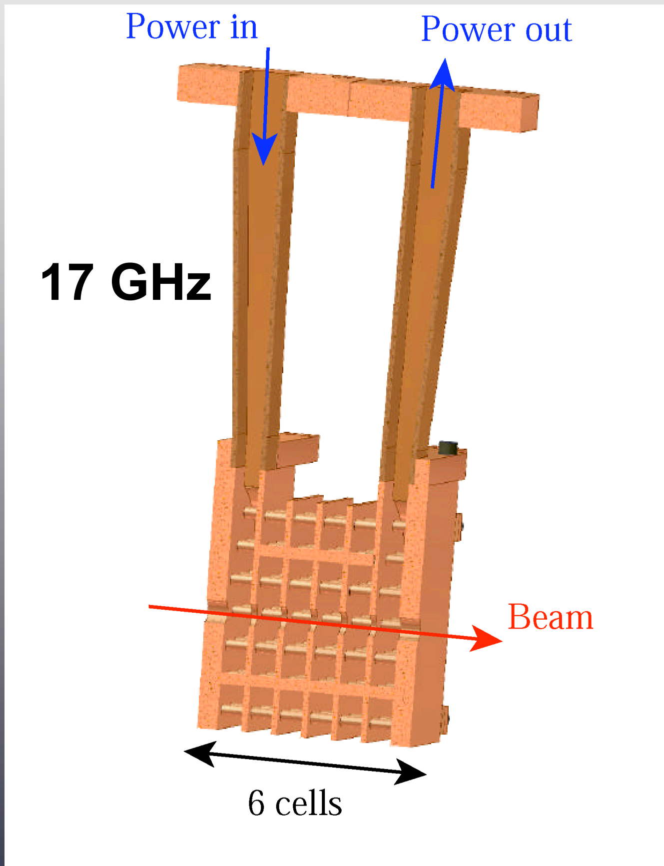
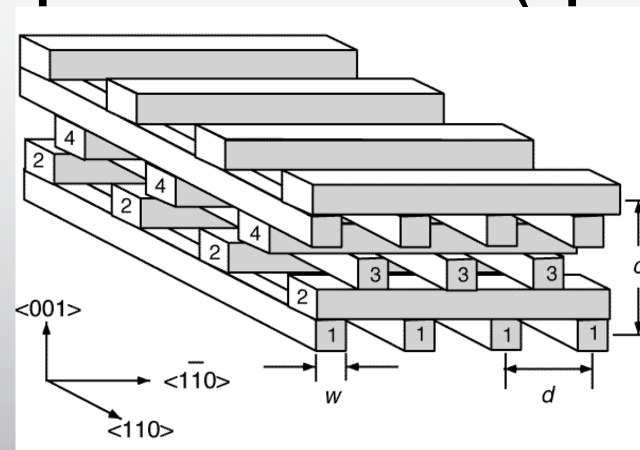
MIT K-band and SLAC W-band/Optical PBGA's

- Cold test completed, hot test in Aug. '04
- Predict 1 MeV gain on 10-MeV input beam (35 MV/m)

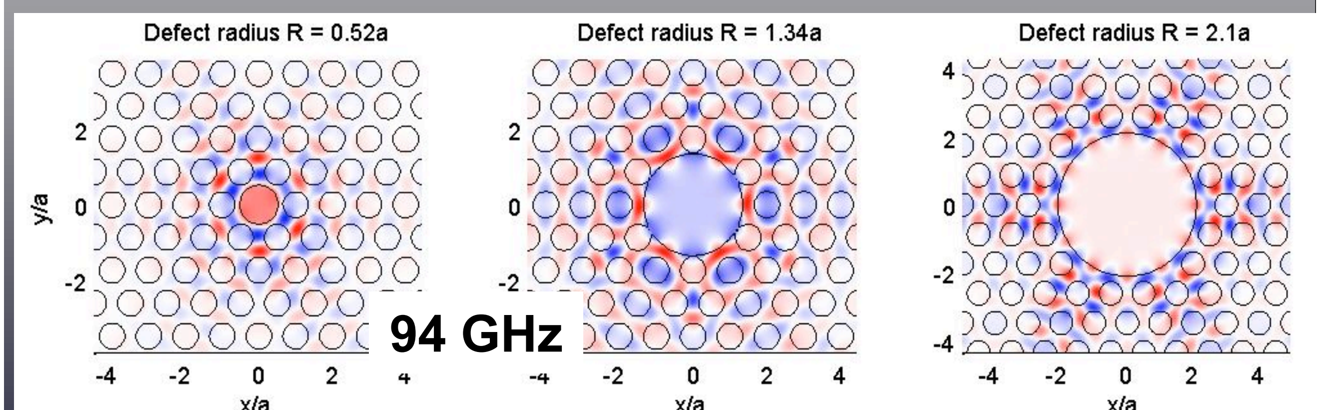


3D planar structures (optical)



2D fiber structures in silica (W-band)

Modes found for several defect radii



Recent IFEL Experiments

STELLA (ATF/BNL)

Observed >20% energy gain and up to 80% trapping efficiency

Observed energy width of accelerated electrons as low as 0.36% (1σ)

Demonstrated ability to control microbunch phase using chicane

Model agrees well with data

NEPTUNE (UCLA)

14.5 MeV e-beam and 400 GW CO2 laser

Demonstrated 150% energy gain (>20 MeV)

Demonstrated accelerating gradient ~70 MeV/m and 10 pC trapped

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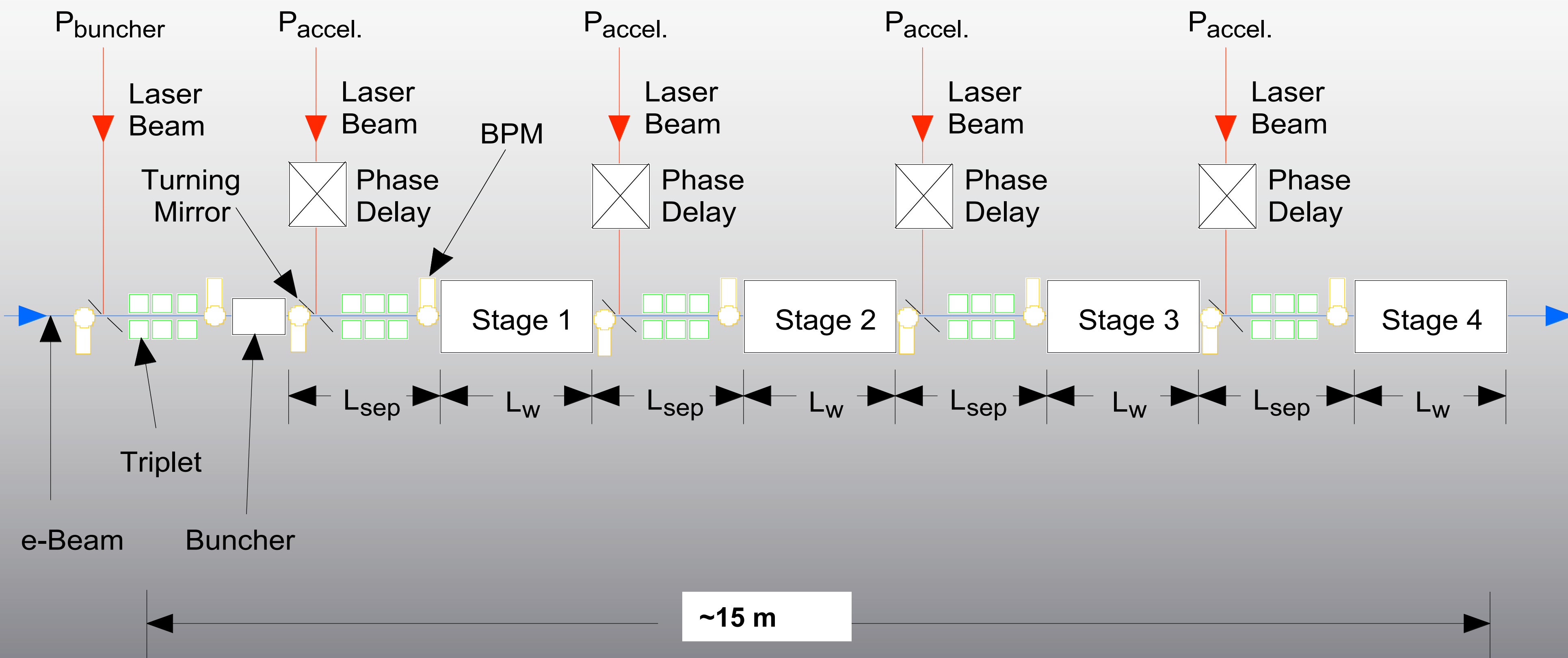
Schematic of 1-GeV IFEL Accelerator



Drive laser: 1.06 μm, 30 fs, 10 TW
Macro pulse: 50-100 MeV, 1 ps, 1 nC, ε ~1.5 mm mrad, σ_E/E ~0.03%
Micro pulses at IFEL exit: 0.3 fs, 3 pC (10 kA)

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VLA-related Efforts

Novel VLA idea

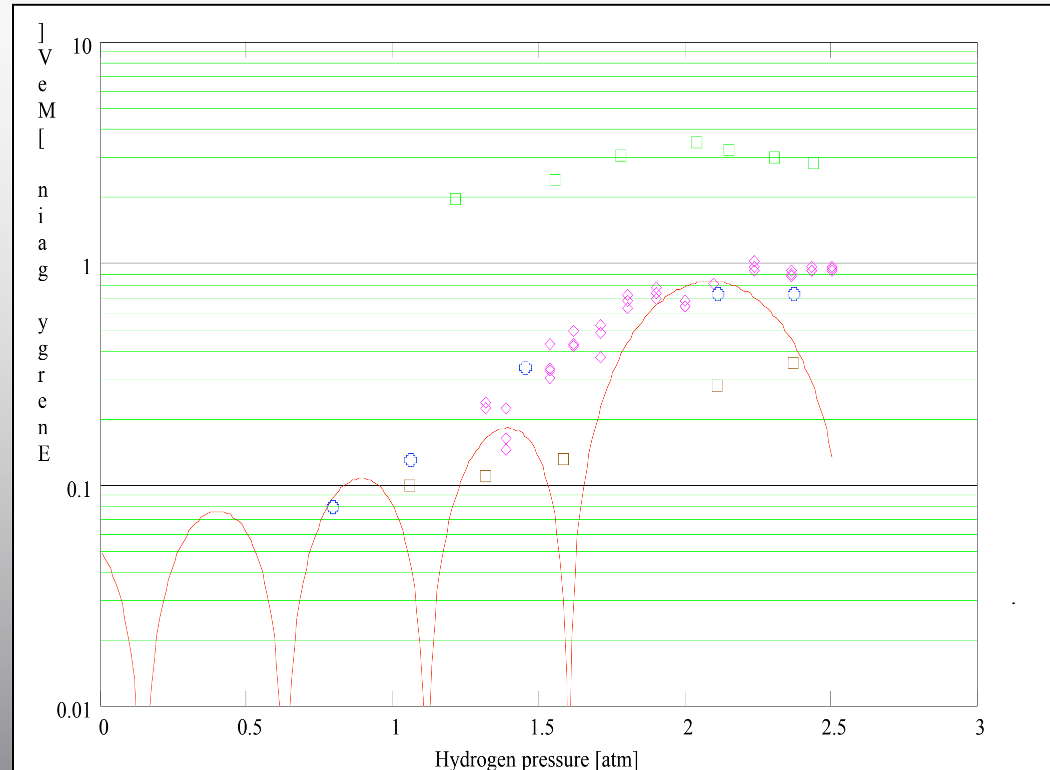
Energy gain can be a few GeV with ultra-intensive laser (a_0~100)

Electron trajectory is curved w.r.t. *z*-axis in this VLA.

Initial electron energy ~ 5-20 MeV

Electron incident angle w.r.t. laser propagation ~ tan (θ) ~ 0.1

Laser-intensity threshold $a_0 \geq 4$ for gain



VLA experiment at ATF: Will use ICA (inverse Cerenkov acceleration) as means to check timing and spatial overlap, then pump out gas to observe VLA effect.

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Summary

Outstanding progress being made in many areas of research

- DWA: Hardware tested, new experiments planned, new ideas developed
- PBGA: Hardware constructed, hot tests later this summer
- IFEL: Becoming "workhorse" provider of microbunches
- VLA: Proof-of-principle experiments in progress

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Thanks to many colleagues and contributors

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