EM Structure-Based Accelerators Working Group - Summary

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STI OPTRONICS

BERKELEY LAB

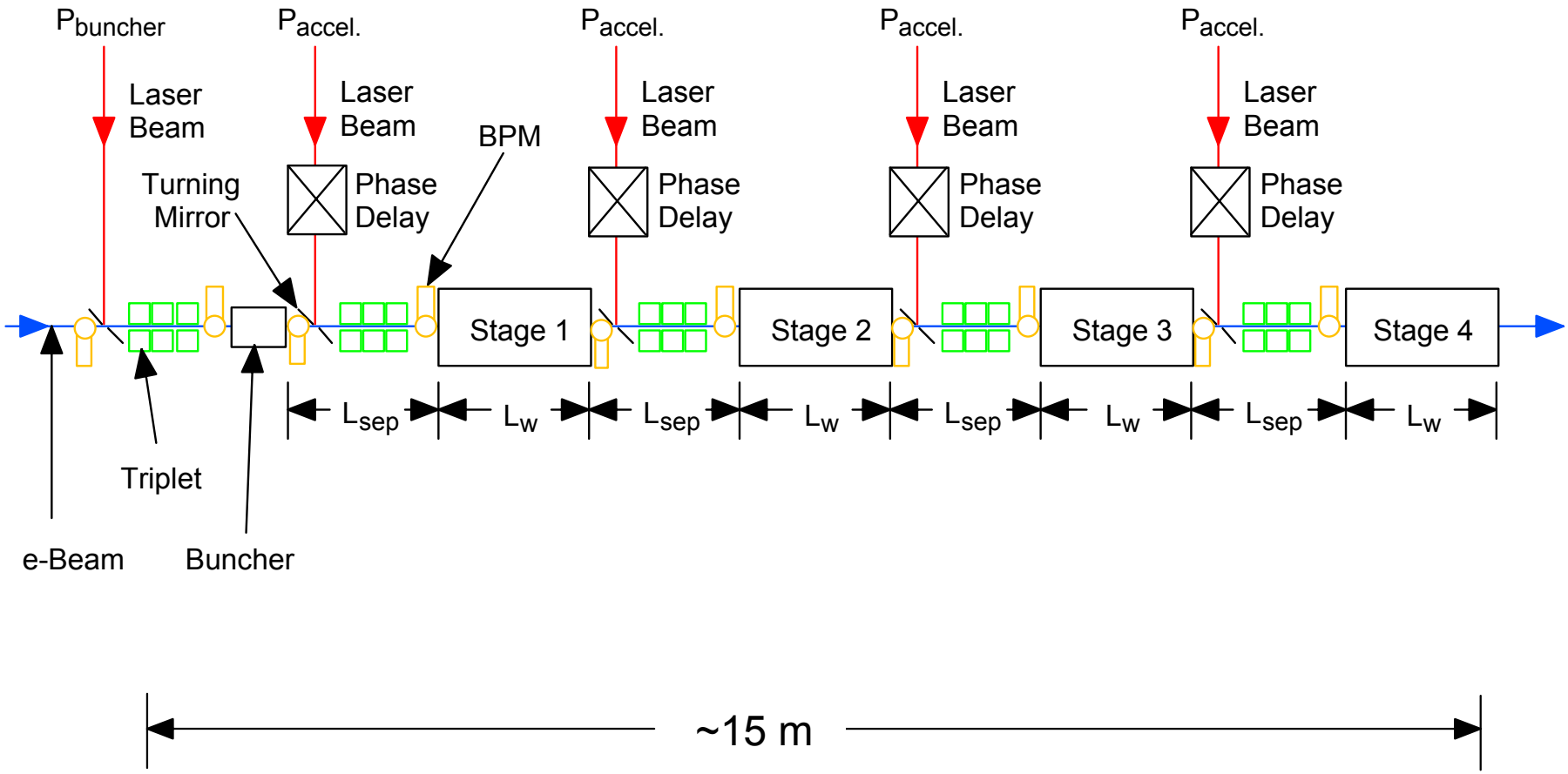
Summary of WG Activity and Results

- Excellent number of oral and poster presentations
  - 4 invited papers, including two 1-GeV strawmen designs
  - 27 contributed papers
- Significant 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
- WG spent ~50% of its time working on 1-GeV IFEL and DWA strawmen designs
  - Decided on representative application for each mechanism
  - Decided on options for satisfying application requirements
  - Sometimes required developing new ideas to satisfy needs

1-GeV IFEL Driver for SASE FEL

- Gerry Dugan reviewed needs for synchrotron radiation facilities
  - Need to produce high average currents with high efficiency
  - Tough to compete with current energy recovery linac concepts
  - More suitable role may be as compact drivers for SASE FELs (Self-Amplified Spontaneous Emission)
    - Few 100's MeV to few GeV
    - Low ε_n (~few mm-mrad)
    - Short bunch length (~3-10 μm)
    - High peak current (few kA)
    - Small energy spread (<0.05%)
  - Advance accelerators have advantages over conventional systems
    - Compact system
    - Naturally short bunches
- Decided to focus 1-GeV IFEL strawman design on SASE FEL

Schematic of 1-GeV IFEL Accelerator



Issues and Design Parameters for IFEL

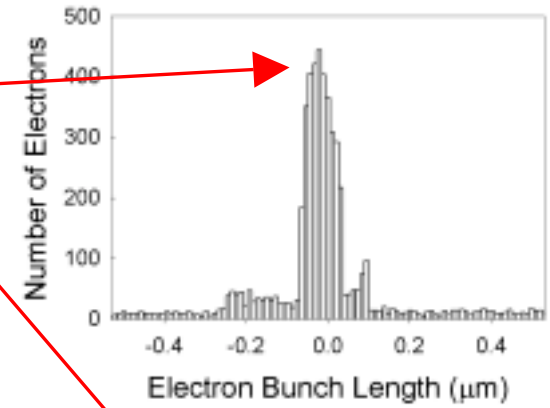
- IFEL already satisfies many SASE FEL injector requirements
  - Few 100's MeV to few GeV – IFEL okay
  - Low ε_n (~few mm-mrad) – IFEL okay
    - Initial analysis by Chris Sears indicates small increase in emittance
  - Short bunch length (~3-10 μm) – IFEL okay
  - High peak current (few kA) – IFEL should be okay, but space-charge is an issue
  - Small energy spread (<0.05%) – Important issue
- Basic parameters for laser driver for IFEL
  - Laser wavelength = 1.06 μm (10.6 μm still viable alternative choice)
  - Laser peak power = 10 TW
  - Laser pulse length = 30 fs (1 ps better for several reasons)
    - Longer pulse length allows more wiggler periods to avoid pulse slippage
    - Makes it easier to have *e*-beam pulse length ≤ laser pulse length
  - Laser repetition rate = 10 Hz (but may need higher PRF to achieve desired beam average power)

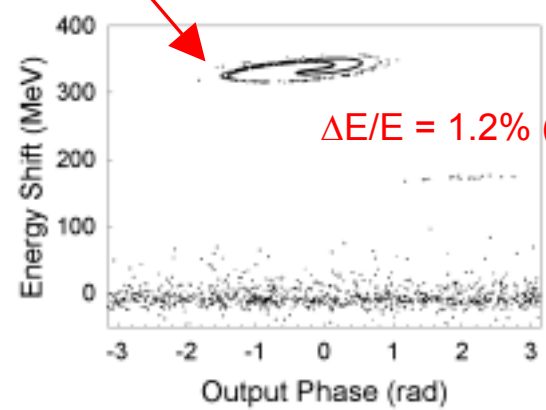
1-GeV IFEL Parameters (cont.)

- Input *e*-beam parameters (assume ATF-like linac)
  - Energy = 50-100 MeV
  - Intrinsic energy spread = 0.03%
  - *E*-beam macropulse charage = 1 nC @ 1 ps *e*-beam pulse length
  - Normalized emittance = 1.5 mm-mrad
  - Repetition rate is limited by laser rep. rate = 10 Hz
- Microbunch characteristics
  - Bunch length ~ 0.3 fs (100 nm length)
  - Microbunch charge at output of IFEL system = 3 pC
  - Peak current in one microbunch = 10 kA @ 0.3 fs
- Modeling of a 1-GeV IFEL was done earlier using STI and UCLA codes
  - Indicates high trapping efficiency (~80%) should be feasible
  - Control of *e*-beam focusing between stages is important
- About 100 SASE wavelengths within each microbunch implies slippage is not a problem

Possible Way to Achieve Ultra-narrow Energy Spread (~0.03%)

- **Need** to have small microbunch length **and** narrow energy spread at output
  - Easy to have short microbunch
  - But, energy spread can be relatively large
- Possible solution
  - Adjust wiggler taper to gradually increase resonant phase angle in subsequent stages
  - This decreases bucket depth, which decreases energy spread
  - The hope is trapped microbunch will maintain same bunch length
- Possible issues with solution
  - Trapping efficiency may suffer
  - Longitudinal space-charge spreading - may be mitigated by using high initial *e*-beam energy



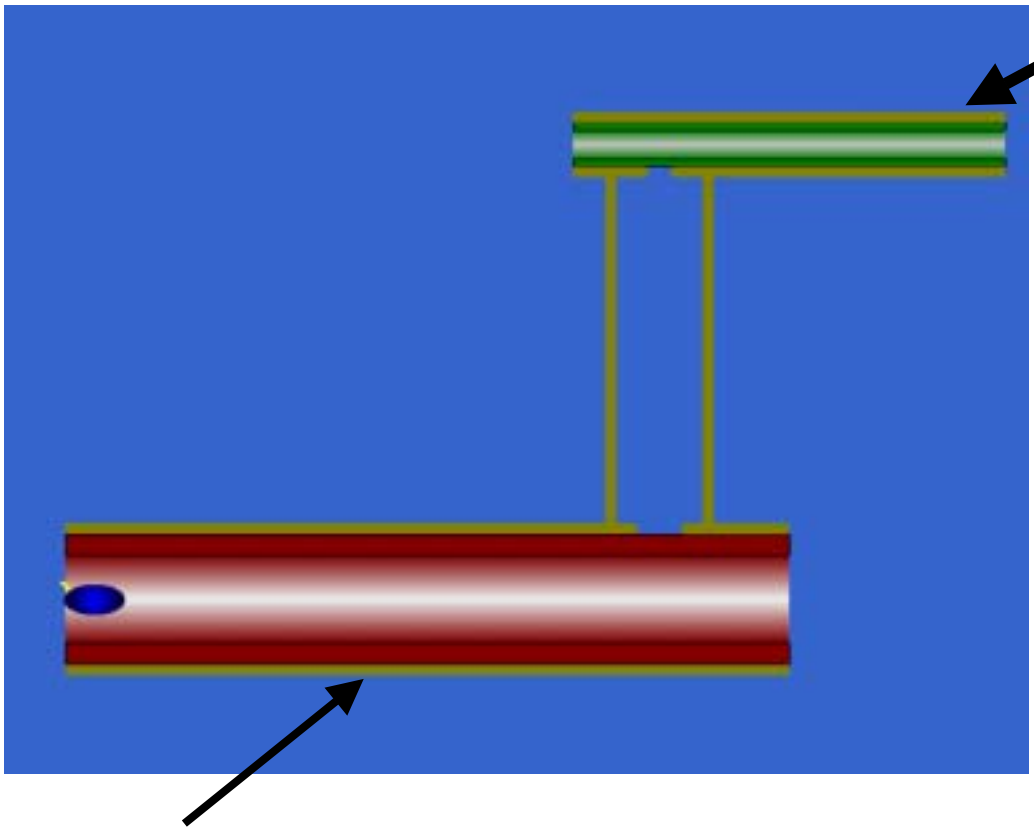


$\Delta E/E = 1.2\% \ (1\sigma)$

1-GeV DWA Module

- 1-GeV DWA module can be used for different applications
  - Multi-TeV collider
  - Energy transformer from high-current/low-voltage beam to low-current/high-voltage beam
- Advantages and issues related to DWA
  - Advantages: simple geometry, easy to tune and control parameters, can be powered by beam, HOM damping easy
  - Fundamental issue: breakdown of dielectric (current emphasis in research)
- Several approaches possible
  - Dielectric Two-Beam Accelerator (TBA) (chosen for this design exercise)
  - Multi-stage DWA
  - Enhanced transformer ratio using ramped bunch train

Two Beam Acceleration Scheme



High gradient,
high impedance, structure
Low current beam

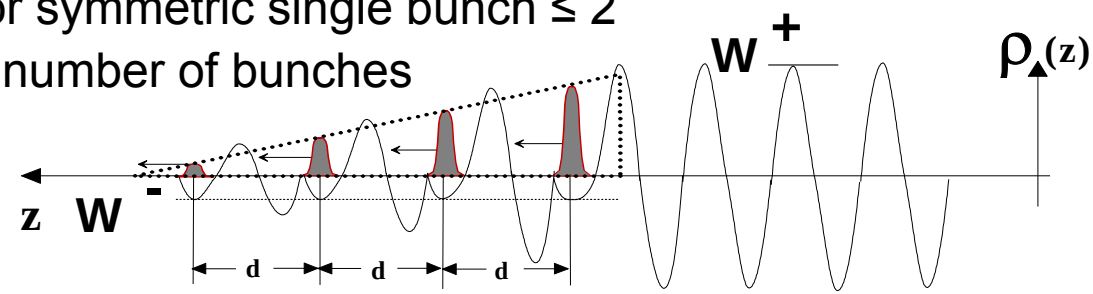
High current low energy beam in low impedance structure

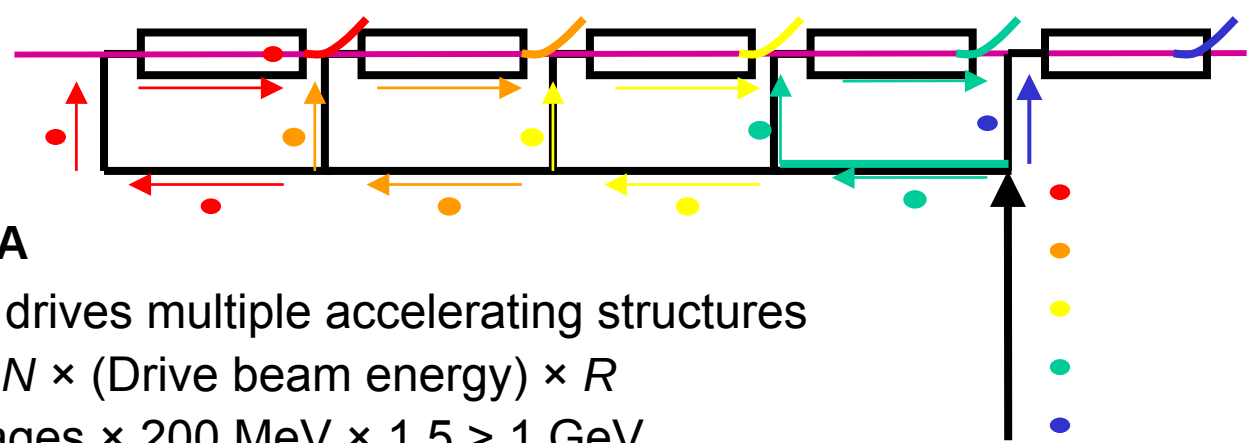
1-GeV TBA Module Parameters

- 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 gradient: 333 MV/m
  - Power requirement: 500 MW
  - Accelerator length: 3 meter
  - RF pulse length: 6 x 16 ns

1-GeV DWA Collinear Options

- **Enhanced transformer** using a ramped, bunched train
  - Transformer ratio R for symmetric single bunch ≤ 2
  - $R \leq 2 \times N_{ramp}$, N_{ramp} = number of bunches

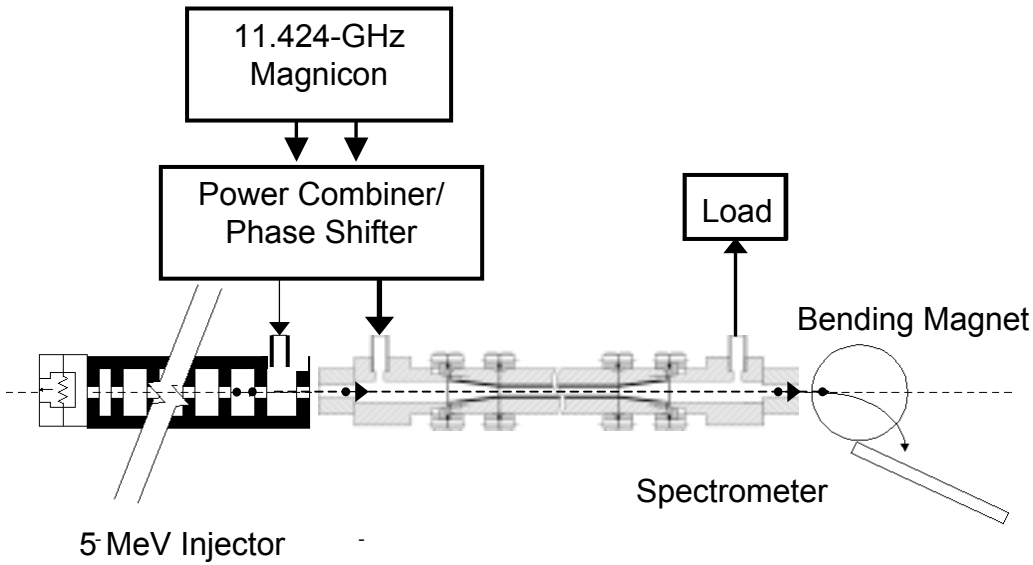




- **Multi-stage DWA**
  - Single injector drives multiple accelerating structures
  - Energy gain = N × (Drive beam energy) × R
  - Example: 5 stages × 200 MeV × 1.5 > 1 GeV

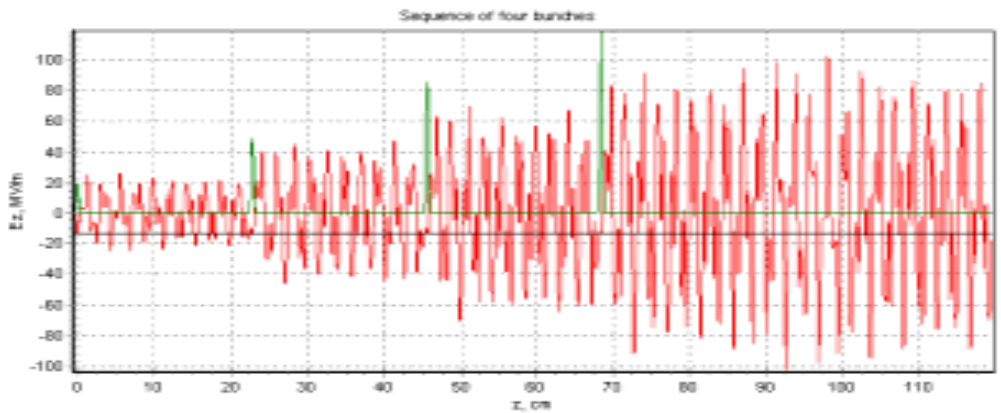
20-MeV Dielectric-Loaded Accelerator Test Facilty at NRL

- 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



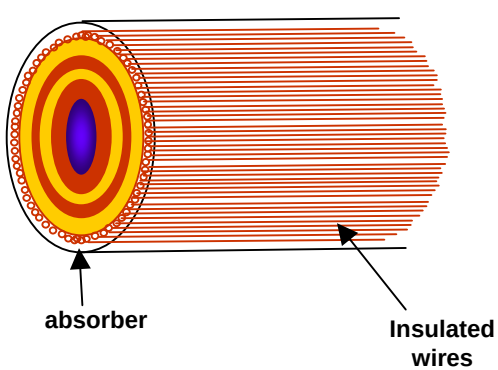
- **AWA Enhanced Transformer Ratio Experiment** (Kanareykin)
  - Proof-of-principal to obtain $R > 2$
  - 13.625 GHz structure with FODO lattice
  - Laser beamsplitter produces 2-6-10-14 nC bunch drive train

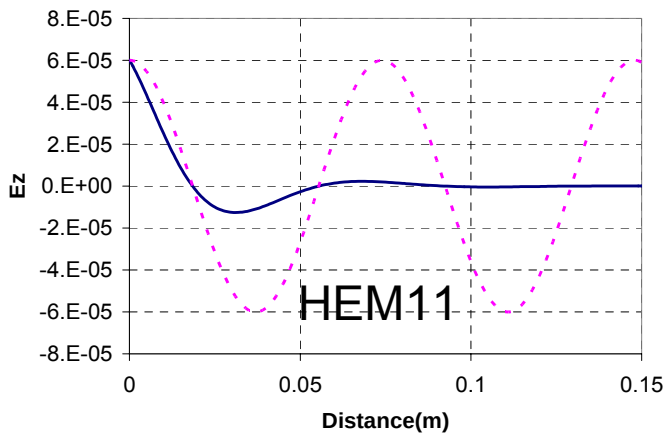
a=0.1 cm, b=0.268 cm, ε=16,
σ_z=0.15 cm, **(15-39-67-93) nC**,
R=7.27, E=104. 3 MV/m



- **On-going DLA Studies** (Jing)

- Multilayer dielectric loaded structures have improved transmission in fundamental
- Ferrite loaded DLAs provide BBU (Beam Breakup) HOM suppression



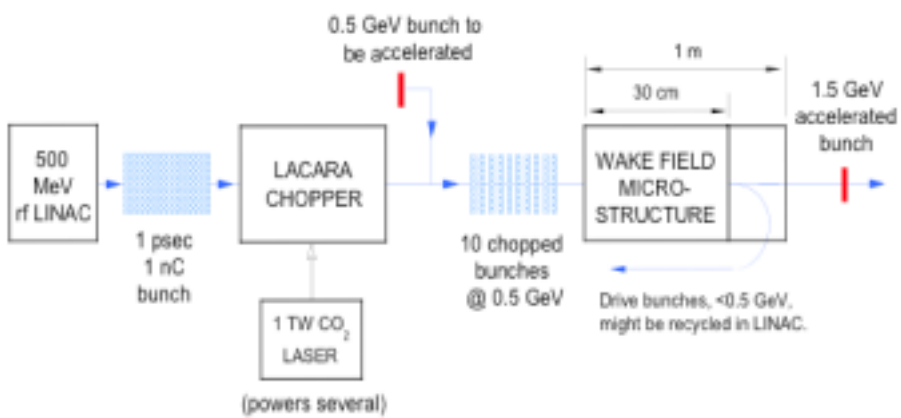


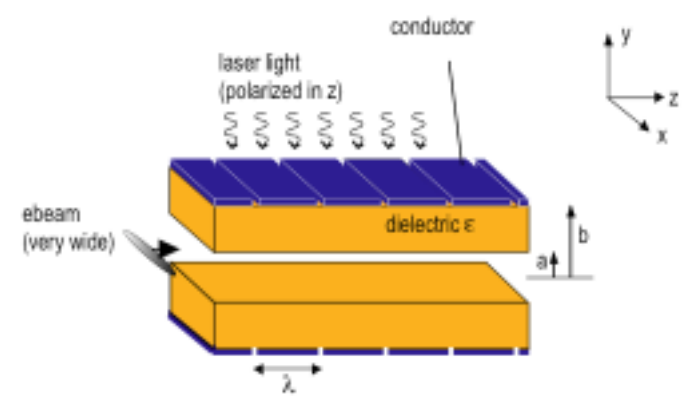
Planar Dielectric Structures Have Possible Advantages

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

- Planar fed by optically bunched train (T. Marshall)
  - Wake field amplitudes to 1.1 GeV/m
  - BBU studies: stability over 10's cm

- Novel resonant dielectric structure excited with THz radiation (R. Yoder)
  - Multi-layer structures for IR loading
  - ~100 MeV/m from ~100 MW excitation

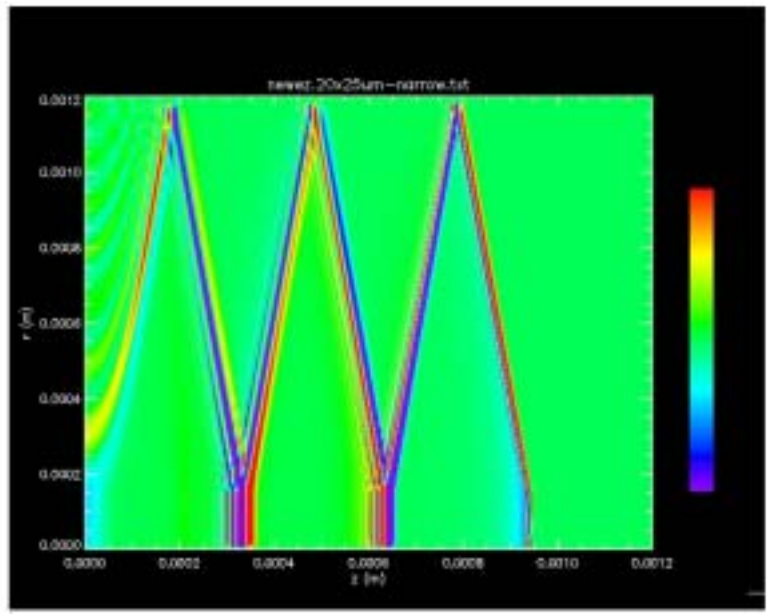




Other DWA Efforts

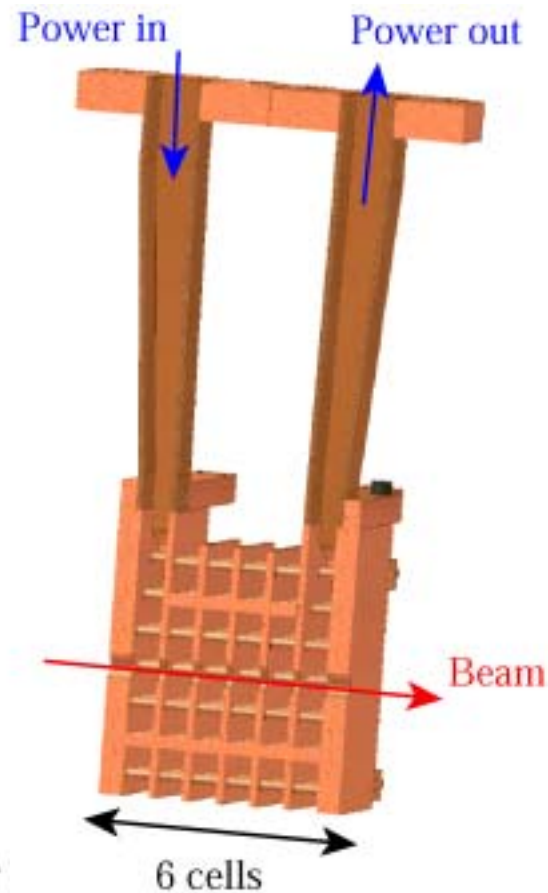
- 3-D analysis of Vavilov-Cherenkov and transition radiation in planar dielectric generated analyzed for single and train of electron bunches (Marshall)

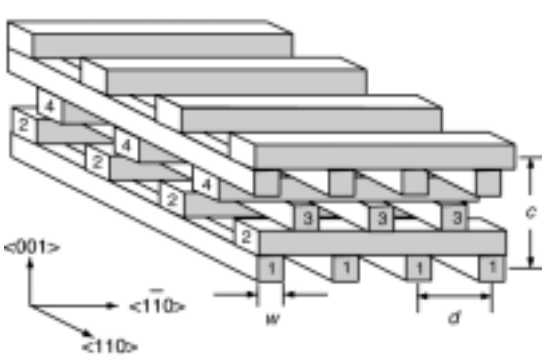
- Cerenkov accelerator studies by UCLA at E-163 (Rosenzweig)
  - Examine structure fabrication and field limits (λ dependence, wake vs. optical)

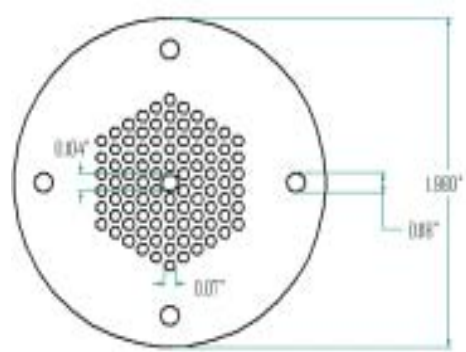


PBGA-related Efforts

- Theory and status of X/K-band and laser-driven PBGA accelerators reviewed (E. Smirnova)
- New analytical model developed to supplement existing numerical models (K. Samokhvalova)
- MIT K-band PBGA accelerator fabricated (E. Smirnova)
  - Cold test underway, hot test in Aug. '04
  - Predict 1 MeV gain on 10-MeV input beam (35 MV/m)
- SLAC developing laser-driven "woodpile" and W-band fiber PBGA structure (B. Cowan)





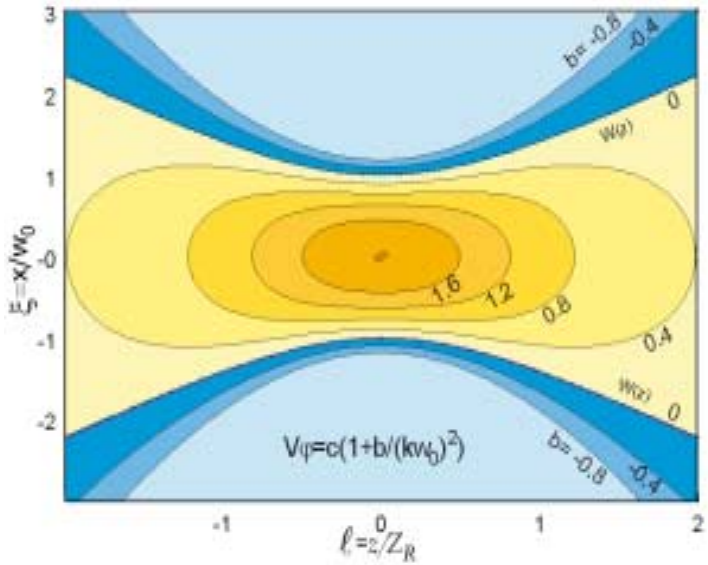


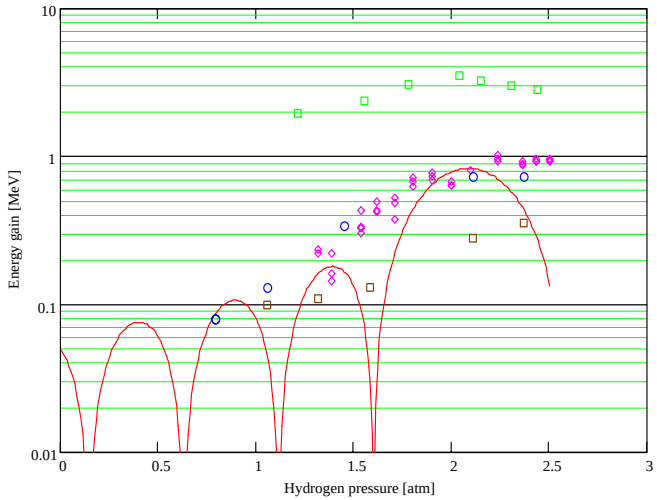
IFEL-related Efforts

- Detailed comparisons between data and model presented for STELLA (W. Kimura)
  - Energy spectrums agree well, including for different phase delays between laser beam and microbunches in second IFEL
  - Model energy-phase plots useful in understanding trapping and acceleration process
- E-163 (NLCTA) IFEL/chicane microbuncher for laser acceleration tests (C. Sears)
- USC/BNL developing design for IFEL buncher to feed into PWA (T. Kallos)
  - Probably similar to STELLA buncher
- UCLA making THz IFEL buncher to produce microbunches to feed into beat-wave accelerator (J. Sung)
  - Mix 10.3 μm and 10.6 μm in GaAs to generate 340 μm (same as beat-wave wavelength) to send into IFEL wiggler

VLA-related Efforts

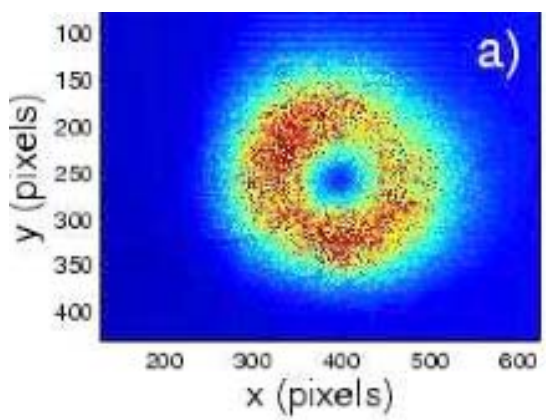
- **Novel VLA experiment** (F. Zhou)
  - Energy gain can be a few GeV with ultra-intensive laser (a_0~100)
  - Electron trajectory is curved w.r.t. *z*-axis in this VLA.
  - Initial electron energy ~ 5-20 MeV
  - Electron incident angle w.r.t. laser propagation ~ tan (θ) ~ 0.1
  - Laser-intensity threshold $a_0 \geq 4$
- **VLA experiment at ATF** (V. Yakimenko)
  - Will use ICA (inverse Cerenkov acceleration) as means to check timing and spatial overlap
  - Then pump out gas to observe VLA effect

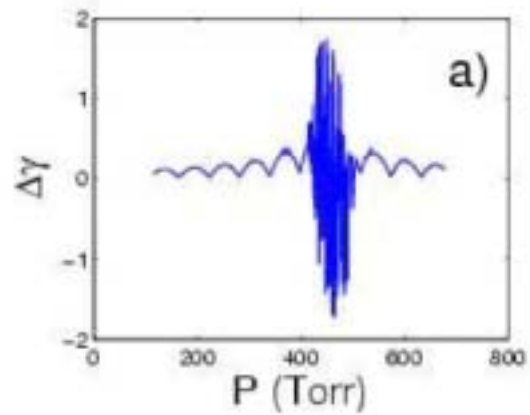




VLA (cont.) + Guns

- Proposal for a laser acceleration experiment at Fermilab (P. Piot)
  - Test of an open iris-loaded structure accelerator (Pantell/Xie)
  - Traveling TEM^*_{01}(donut) mode within a hydrogen gas cell
  - Predict ΔE ~ 5 MeV for 43 MeV electrons





- MIT 17 GHz RF Gun (A. Kesar)
  - 3-cell design
  - Working to improve performance

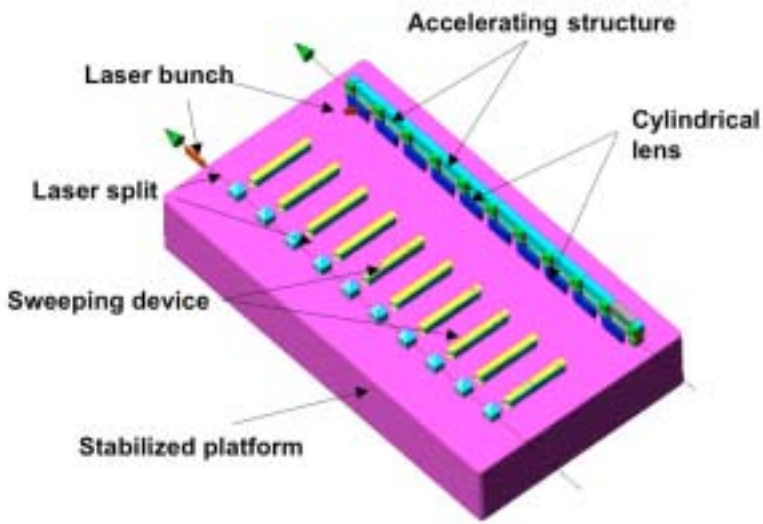
- DULY/UCLA S-band PWT Injector (D. Yu)
  - Polarized beams, cesiated GaAs
  - Operation at 60 MV/m, low dark current
  - Simulations: 1 mm-mrad, 1 nC

Other "Grating"-related Efforts

- S. Zhilkov described novel method to modulate an optical beam by scattering from a ribbon *e*-beam passing above a grating-like structure

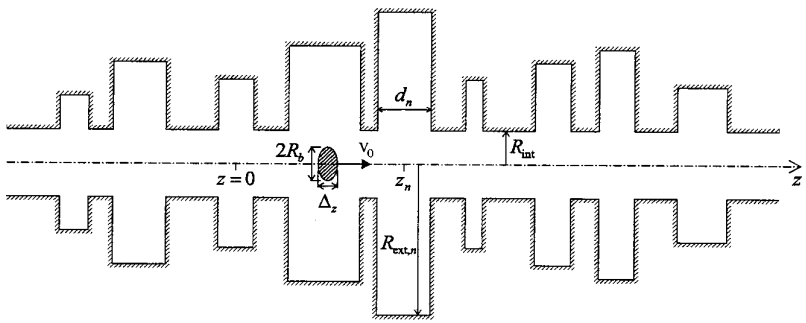
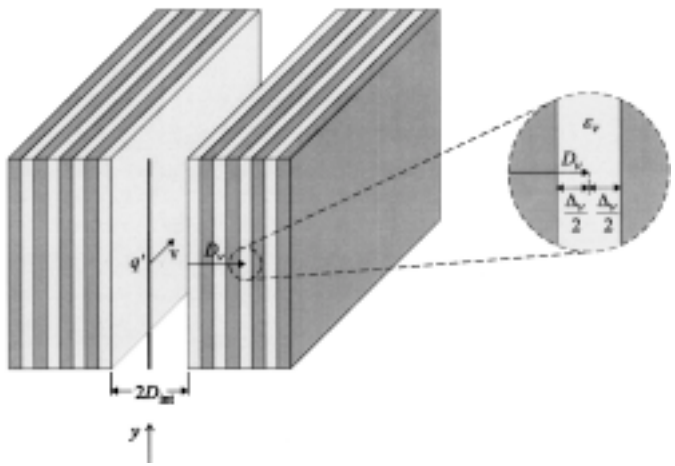
λ	10.6 µm	1.55 µm	500 nm	80 nm
Ω	170 GHz	1.1 THz	3.4 THz	21.25 THz

- A. Mikhailichenko reported on acceleration with a traveling laser focus using short pulse laser
  - Improved version of grating/foxhole scheme
  - May produce high gradients while limiting material damage



Levi's Slide

- Effects of cavity roughness analyzed for metallic cylindrical waveguide with grooves of random width, height, and location (L. Schächter)
  - Amount of average energy emitted per groove varies linearly with roughness parameter
  - Average energy emitted and standard deviation due to roughness is virtually independent of energy when $\gamma > 50$



- Bragg accelerator (L. Schächter)
  - Improves confinement of mode to vacuum region
  - Inner-most layer provides 'stub-tuner' to match modes in 2 regions