EM Based Accelerator Structures Working Group 7

"beyond CLIC…"

WG Leaders: Eric Colby, Pietro Musumeci

Presentations by:

S. Antipov	**A. Cook**	**W. Kimura**	**P. Schoessow**	**M. Thompson**
S. Banna	**B. Cowan**	**M. Lincoln**	**C. Sears**	**S. Tochitsky**
J. Cary	**C. Jing**	**P. Musumeci**	**M. Shapiro**	**A. Tyuktin**
E. Colby	**D. Kaganovich**	**J. Rosenzweig**	**S. Shchelkunoff**	**M. Uesaka**
M. Conde	**A. Kanareykin**	**L. Schächter**	**G. Shvets**	**C. Wang**

Working Group Charge

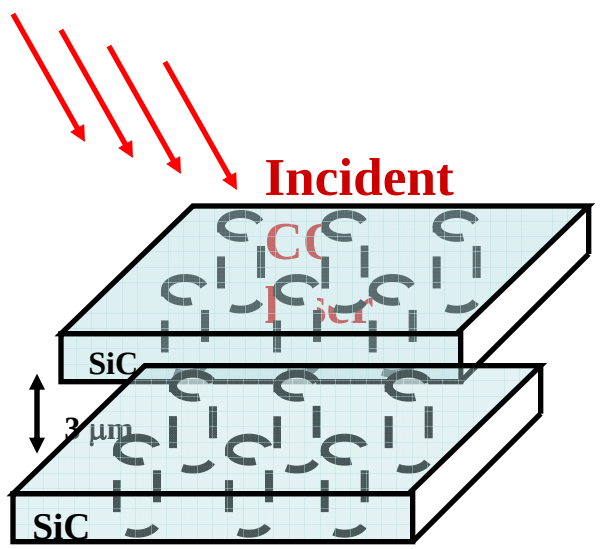
- **Expected Performance**. What is your best estimate for the achievable gradient of your device, the efficiency in converting RF or laser power to beam power, and the capacity to produce high current beams? What emittance dilution is expected on acceleration through your device if it is perfectly aligned, and if it is misaligned?
- **Power Sources.** What power source properties are required? What power sources exist now? What are the prospects for improvement in 5 and 10 years? Who is driving source development? What Advanced Accelerator R&D community involvement will be needed to complete the development of sources that meet all the requirements?
- **Material Properties.** What fundamental material properties influence the achievable gradient and power efficiency? What are the prospects for improvement in 5 and 10 years? What AARD involvement will be needed to push material development? Are there technology developments taking place outside our field that will produce significant improvements
- **Modeling.** What additional theoretical and numerical modeling developments are required to accurately and completely predict device performance?
- **Supporting Technology Development.** What development in supporting technologies (e.g. novel focusing, fabrication techniques, vibration control, alignment, thermal control, etc.)-- beyond that already planned for the ILC-- will be needed to realize an HEP machine from your device?
- **Other Applications.** Can your device be applied to produce more compact or economical industrial accelerators? For example, what are the major components of a machine capable of producing a beam power equal to 10 MeV and 100 Watts? Can your device be applied to produce a novel radiation source? For example, what are the major components of a machine producing 1 GeV and 10^9 ppp at 100 Hz?
- **We will attempt to identify the most pressing shared physical and technical questions, sketch a roadmap, and seek ways to coordinate our efforts.**

Surface wave accelerator based on Silicon Carbide: Theory and Experiment

Gennady Shvets

Two photonic laser-driven accelerators based on SiC are currently pursued:

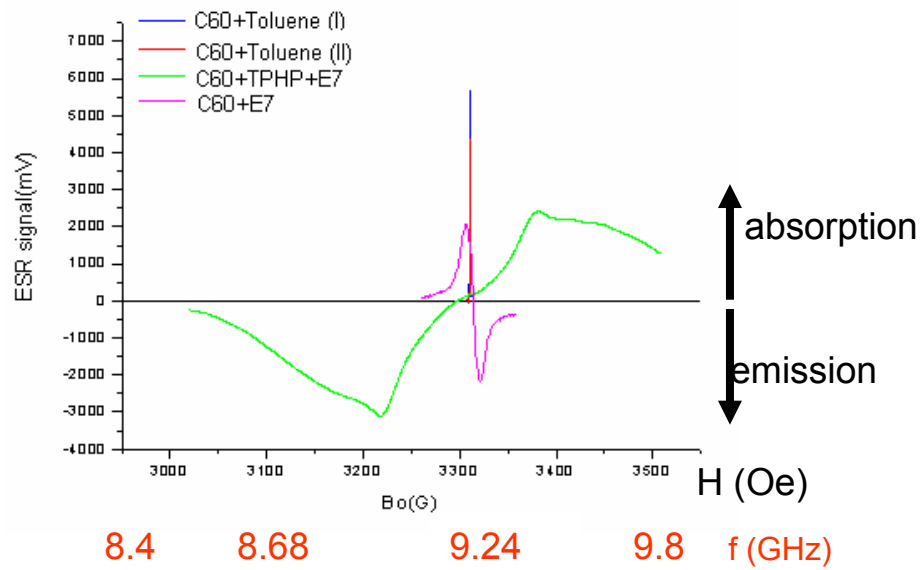
- **SiC films on Si wafers → CO2 laser coupled by grating in Si wafer. Cold tests of the structure underway. Wafer can guide laser pulse and power multiple cavities → Matrix Accelerator**
- **Suspended ("air-bridged") SiC membranes → laser coupled by an array of holes**



Studies of Particle Acceleration by an Active *Microwave* Medium*

Paul Schoessov

- Recently discovered fullerene based X-band paramagnetic active materials (Blank and Levanon).
- Synthesis and EPR measurements of candidate liquid crystal-fullerene compounds. Identification of materials exhibiting high levels of activity.



Euclid Techlabs LLC

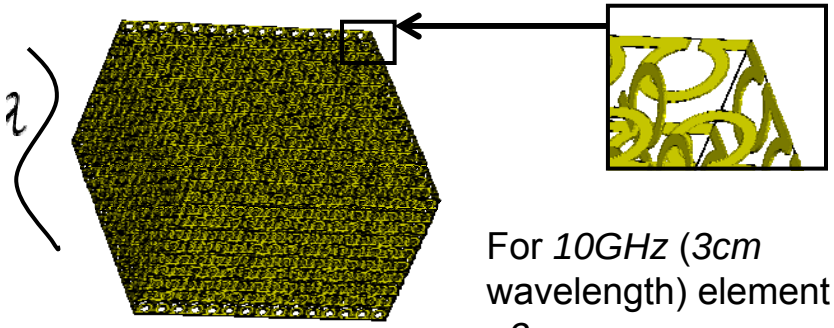
E-Tech

Left-Handed Structures for Accelerator Applications

Sergey Antipov

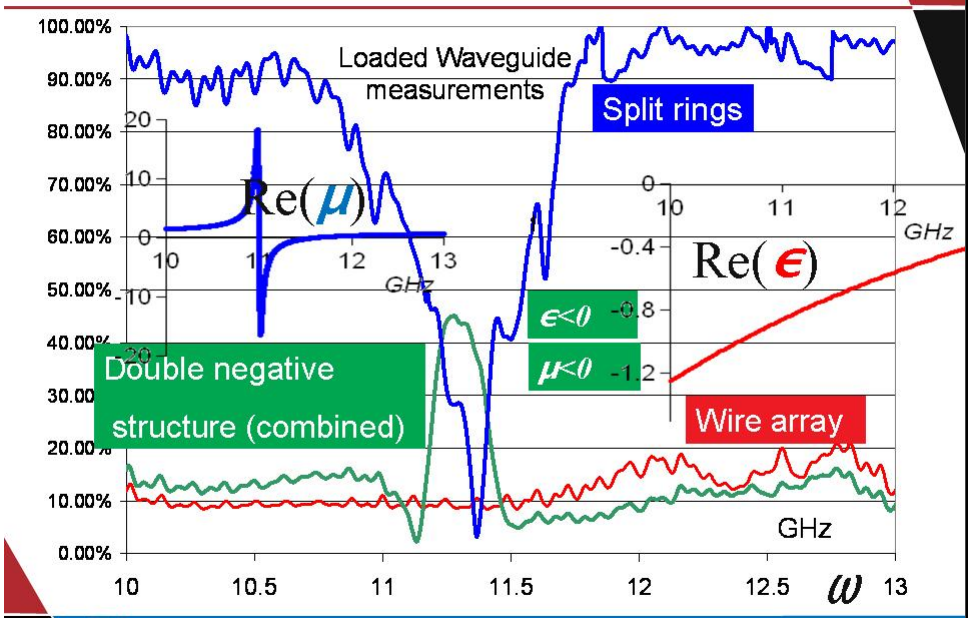
Effective media approximation

$$\lambda >> d \Rightarrow \exists\, \hat{\varepsilon}(\omega) \text{ and } \hat{\mu}(\omega)$$



For *10GHz* (*3cm* wavelength) element size is *~3mm*

TE01 mode in MTM-loaded waveguide (experiment)

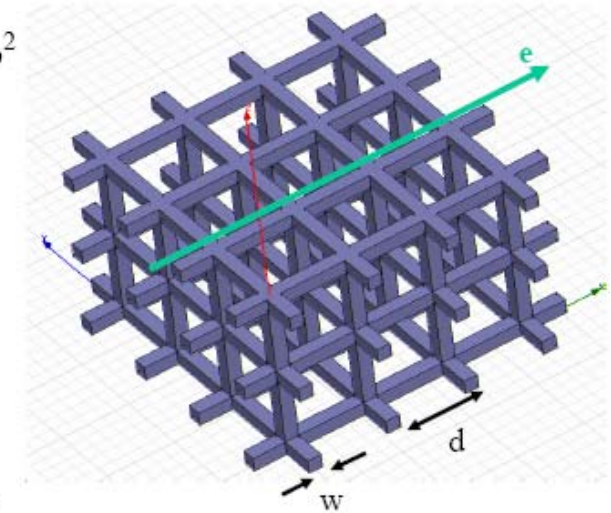


SURFACE WAVES OF METAMATERIALS AND THEIR APPLICATIONS TO ADVANCED ACCELERATORS

M.A. Shapiro

$$\varepsilon_p(\omega) = 1 - \omega_p^2 / \omega^2$$

$$\omega_p = \frac{c}{d}\left(\frac{2\pi}{\ln\frac{d}{w}}\right)^{1/2}$$

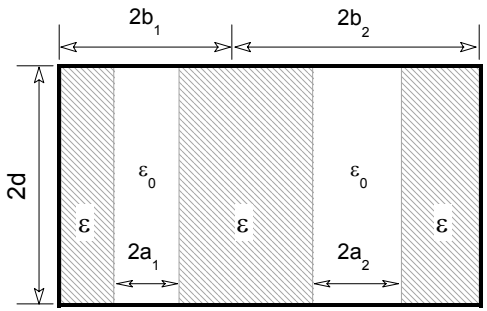


Dimensions:
period d=0.58 cm,
square rod width w=0.1 cm

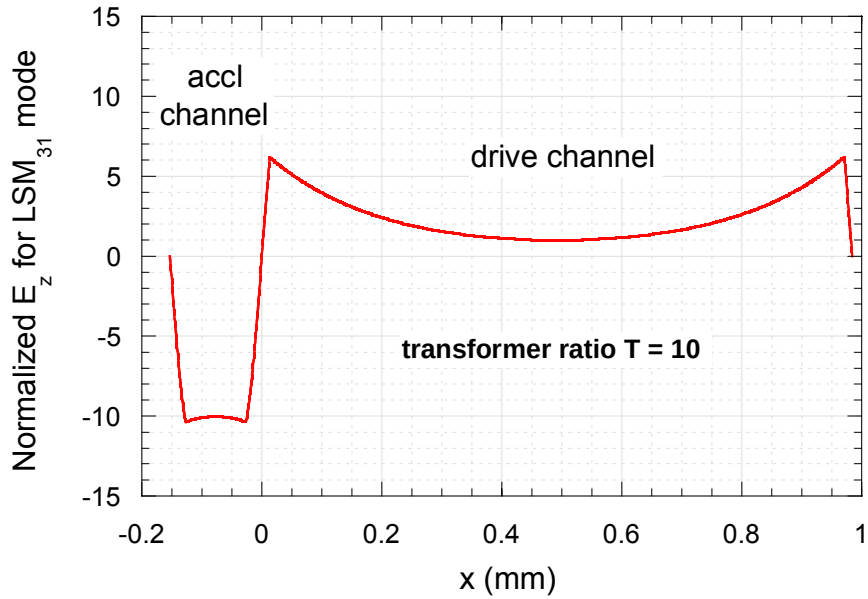
- Surface plasma wave accelerator can be modeled at microwaves using metamaterial – artificial plasma
- Bulk and surface modes of metamaterial calculated
- Equivalent tensor of dielectric permittivity for medium with spatial dispersion determined
- Surface mode resonance at $\omega=\omega_p$ (not $\omega=\omega_p/\sqrt{2}$) due to spatial dispersion

RECTANGULAR DIELECTRIC-LOADED STRUCTURES FOR ACHIEVING HIGH ACCELERATION GRADIENTS

C. Wang



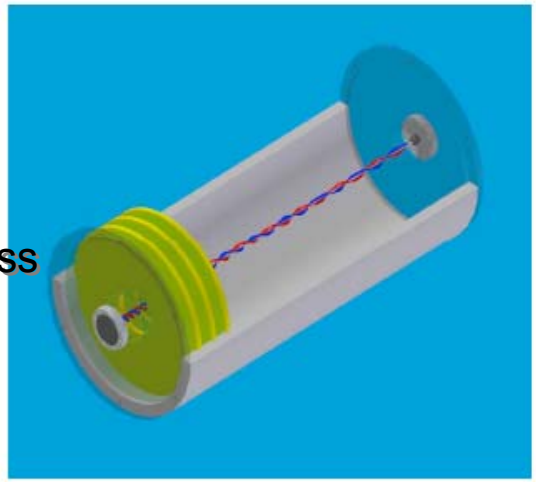
A two-channel acceleration structure is presented, in which a drive beam is in one channel and an accelerated beam is in the other. The RF power produced by the drive bunches in the drive channel are continuously coupled to the acceleration channel.

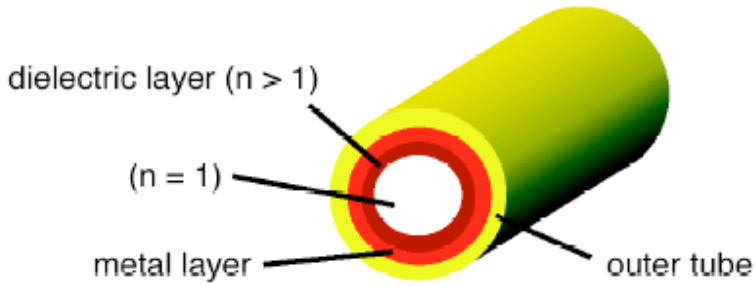


Next Generation IFEL Experiments at the UCLA Neptune Lab

J. B. Rosenzweig

- Helical undulator
  - Bifilar design shown
- Moderate power
  - ~100 GW or less
- Waveguide
  - mm aperture
- Beam confinement
  - Solenoid



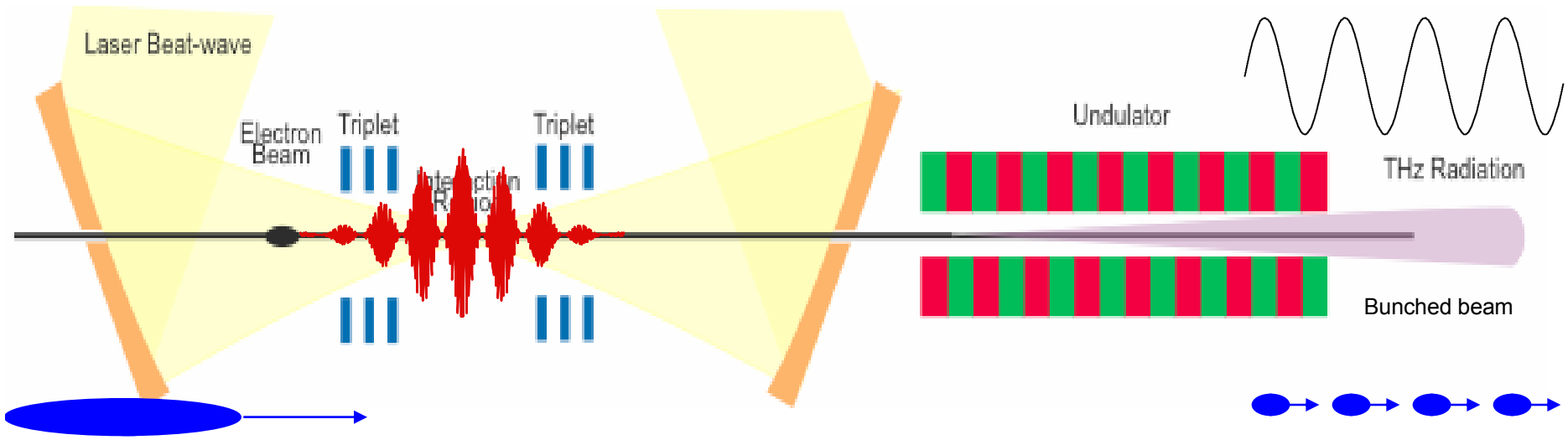


outer tube: **glass** (HGW), plastic metal

inner layers: **Ag/AgI**, Ag/ZnS, Ag/AgBr, Ag/PbF_2

Laser Beat-Wave THz Microbunching/ THz Klystron experiment at Neptune

Sergey Tochitsky, UCLA



Electron Beam	Beat-wave	Undulator
E = 10-14 MeV	λ_1 = 10.6 μm	λ_u = 3.3 cm
σ_E = 10 keV	λ_2 = 9.6 μm	K = 1.8
I = 60 A	w_0 = 240 μm	N_u = 10
ε_N = 16 mm mrad	z_r = 1.5 cm	λ_r = 100 μm
Q = 300 pC	P = 1 TW	

Addressing the charge:

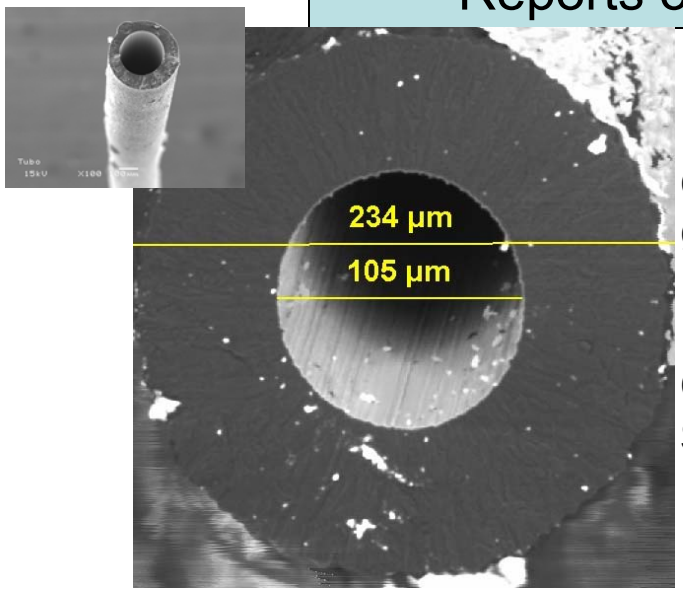
What are the primary physical and technical challenges that must be addressed to demonstrate the viability of THz/Optical accelerators?

Highest Priority

- Coupling and transporting the electron beam through small structures
- Developing THz power sources
- Developing suitable fabrication methods for structures and other components (magnets, diagnostics, EM tranmission components, etc.)
- Injector design
- Engineering limits
  - Breakdown strength of materials (wavelength, material, pulse width)

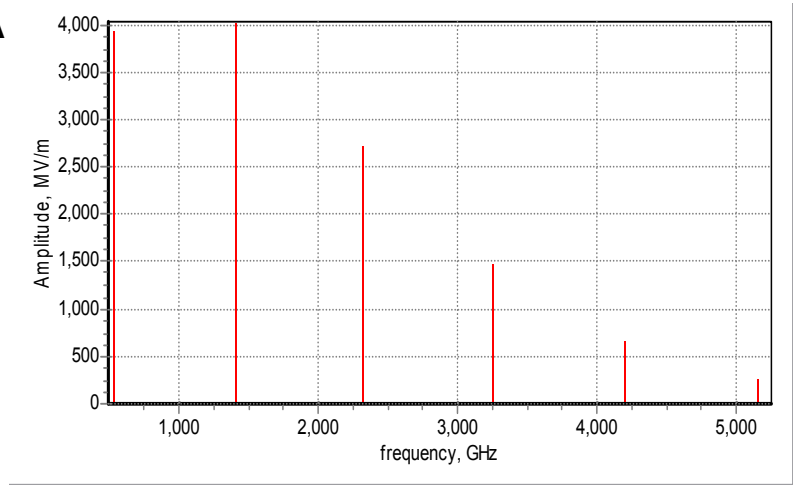
  - Thermal loading/damage/distortion
  - Lorentz detuning– material stress and deflection in highest field areas
  - Radiation damage (gamma, neutron, beam strike)
  - Vibration/Ground motion (alignment and stabilization)
- Diagnostics (Thursday AM I)
- Coupling EM power from free space into the structures without compromising electron beam quality
- Developing needed tools:
  - Analytic and numerical
  - Beam testing facilities
  - Other specialized testing equipment, e.g. material damage testing apparatus
  - In-house fabrication and measurement capability
- Leverage industrial expertise

Reports on Technical Issues: Fabrication



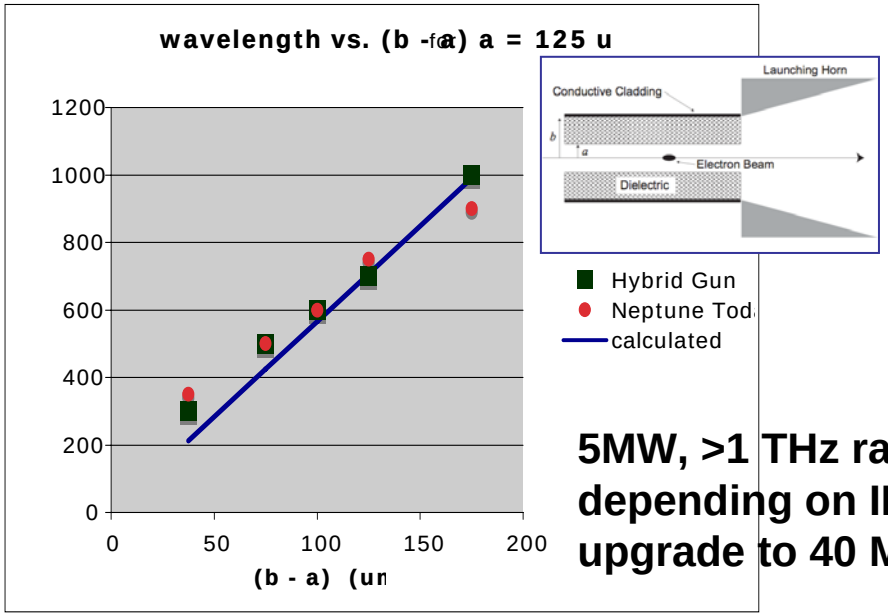
← CVD Diamond DLA developed for THz generation

Computed Wakefield Spectrum →



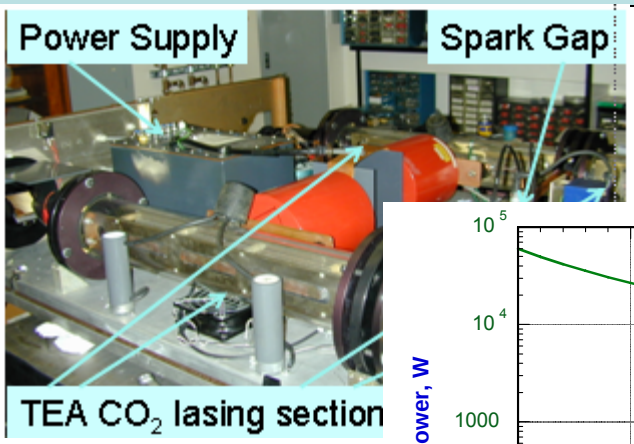
Alexei Kanareykin, Euclid TechLabs

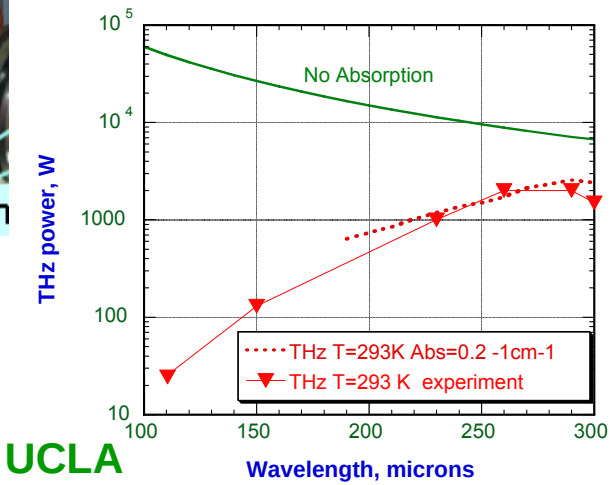
Reports on Technical Issues: THz Radiation Sources



5MW, >1 THz range depending on ID w/ upgrade to 40 MW

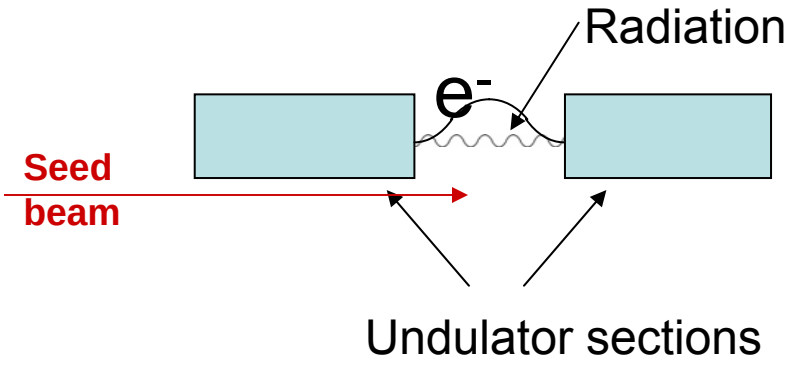
Alan Cook, UCLA

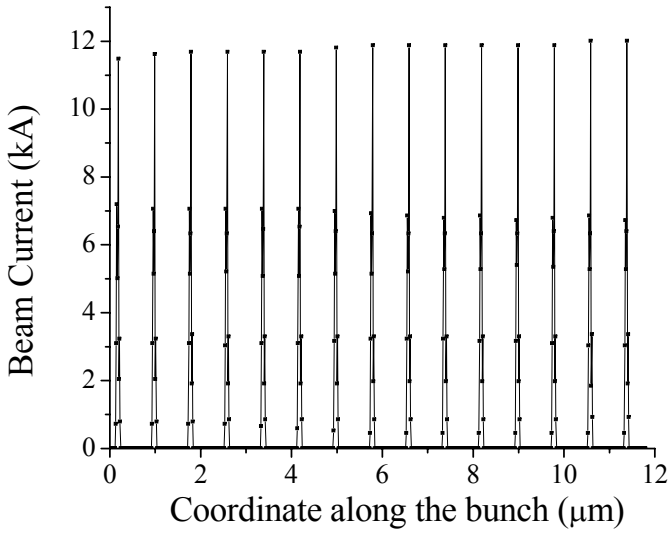




Chieh Sung, UCLA

Reports on Technical Issues: Injectors & Bunchers





IFEL Microbuncher for FEL Seeding

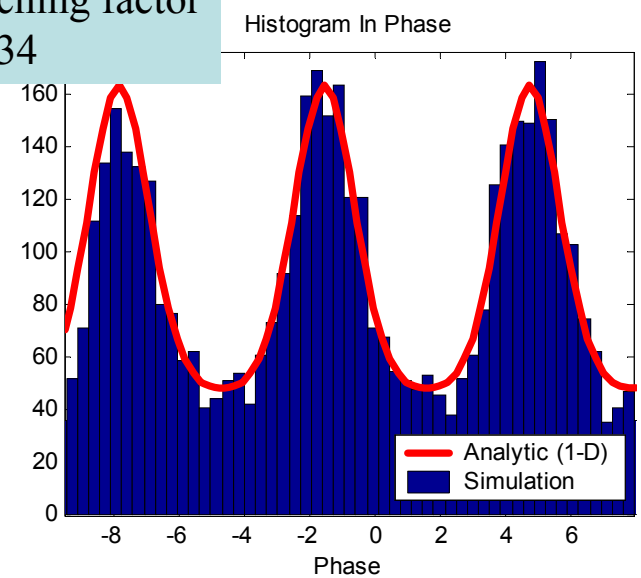
Slippage→Must seed all spikes to give common phase, maximum gain

Pietro Musumeci, INFN

← Fabricated, tested IFEL and chicane for 0.8 m buncher

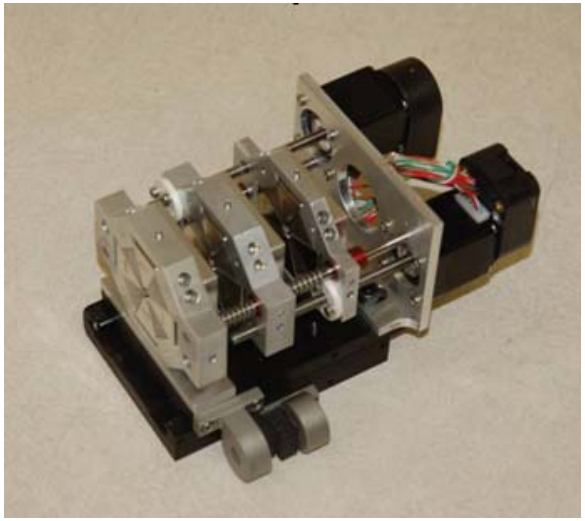
Computed Bunching performance →

Bunching factor β_1=.34



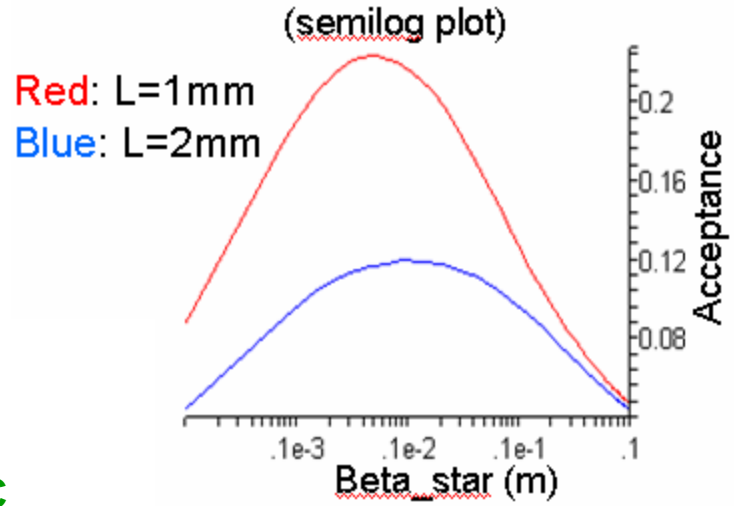
Chris Sears, SLAC

Reports on Technical Issues: Beam Coupling and Transport



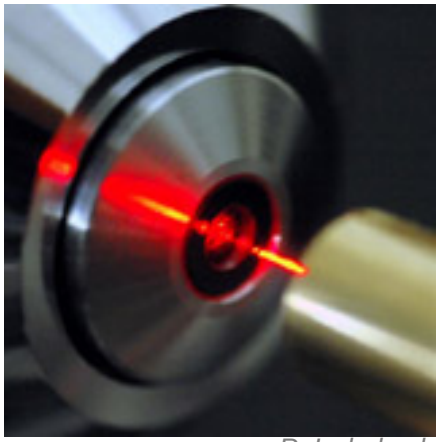
3D Tracking Shows➔ >20% transmission through a structure with R=5μm, L=1mm (ε_x~4 mm-mr)

🡐560 T/m Triplet



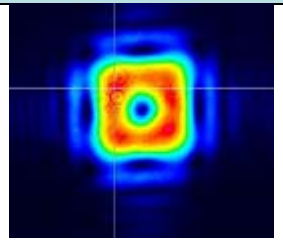
Chris Sears, SLAC

Reports on Technical Issues: Power Coupling



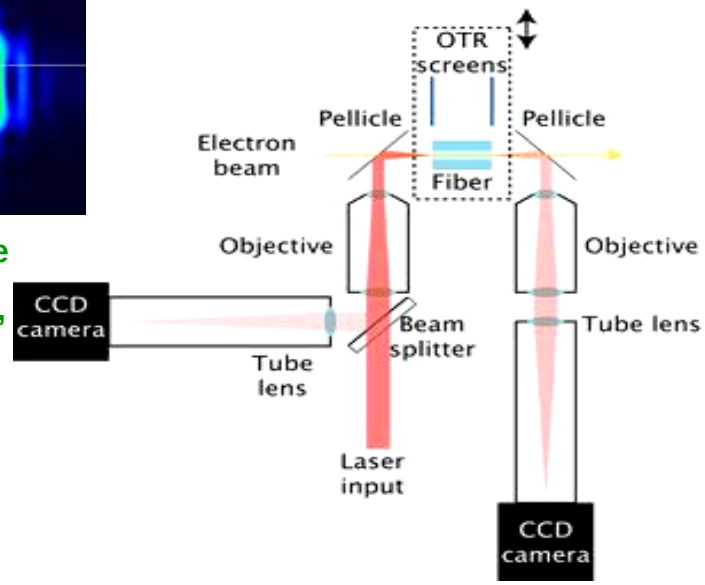
R. Ischebeck

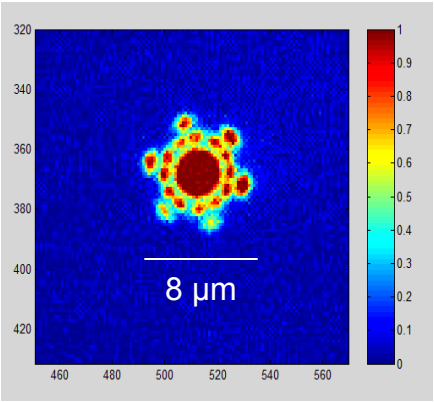
Objective and Illuminated Fiber



TM_{01}^* Mode

T. Plettner, Stanford



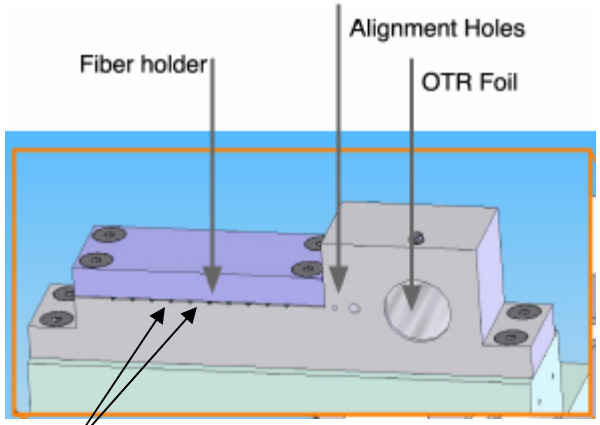


M. Lincoln

Mode Exiting Fiber

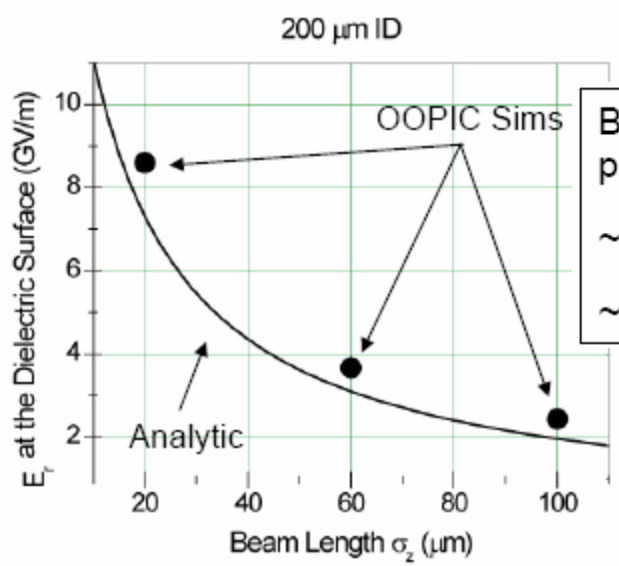
Melissa Lincoln, SLAC

Reports on Technical Issues: Material Damage Studies



Silica capillary tubes

ID 50 & 100 μm x 1 cm



Breakdown fields implied by these preliminary observations :

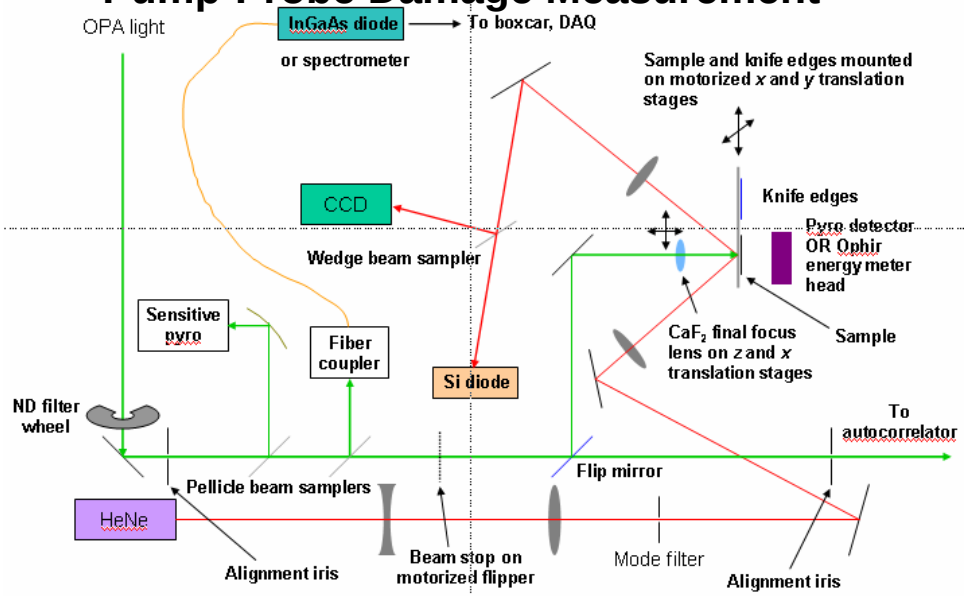
~ 4 GV/m at the dielectric surface

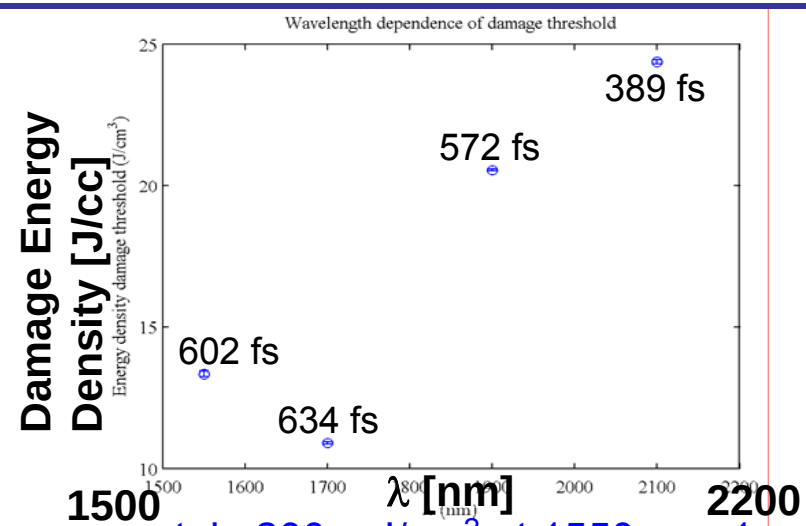
~ 2 GV/m on axis accelerating field

Fundamental: 0.5-0.9 THz

Matt Thompson, LLNL

Pump-Probe Damage Measurement





Silicon can sustain 200 mJ/cm^2 at 1550 nm, 1 ps

Yields ~240 MeV/m accelerating gradient in woodpile structure

Ben Cowan, SLAC

Reports on Technical Issues: Developing Simulation Tools

The Challenge:

- Finding eigenmodes of photonic crystal waveguides is hard
  - High-order mode; Large computational area
- For n "cladding" layers: Memory required ~ n^4, computational time ~ n^6 (!)
- Finding one accelerating mode can take 10^6 CPU seconds (on 2.4 GHz Xeon) even with only 16 grid points/lattice period
- Also: Free-space boundary conditions, to model radiative loss; complex wavenumber
- Damage simulation: Ionization, avalanche, and transport

Ben Cowan, SLAC

A Response:

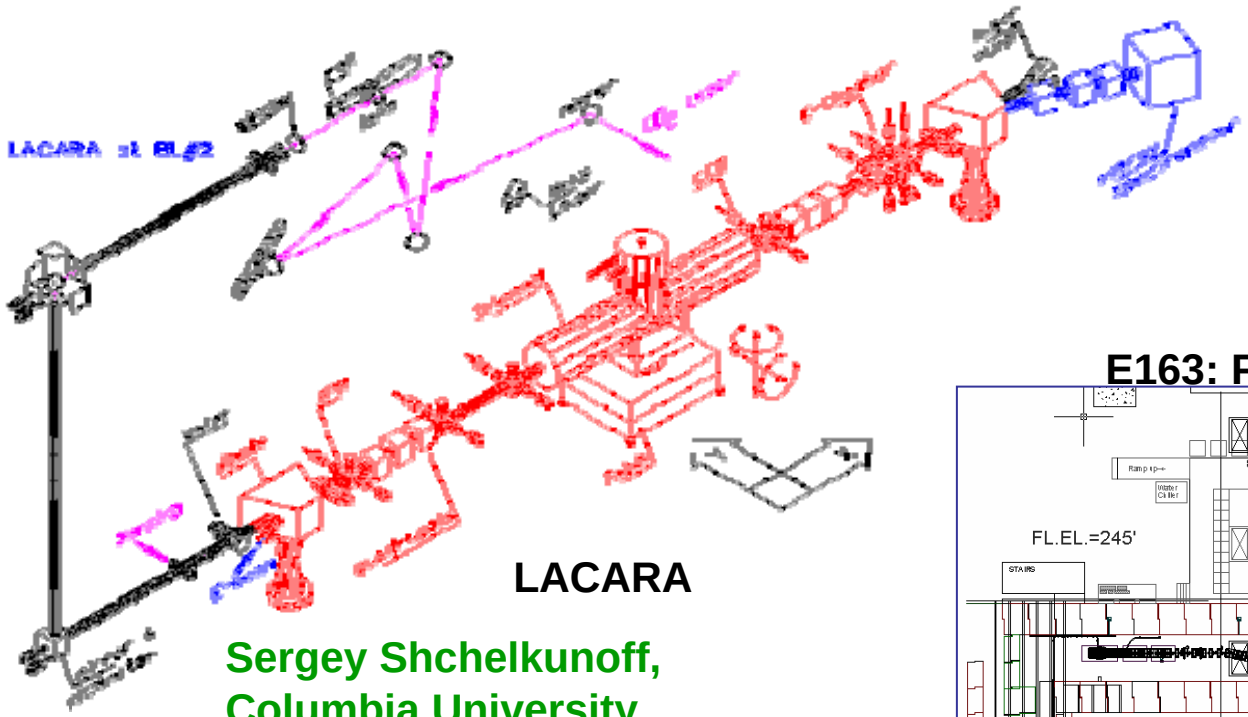
To simulate beams in a PBG device, we turn to VORPAL (originated at CU, now developed mainly at Tech-X Corp.), which simulates:

- charged particles self-consistently with electromagnetic fields
- dielectric materials (coming very soon: tensor dielectrics)
- metal boundaries (coming very soon: better curved boundaries)
- "wave absorbing" boundaries (with PMLs, Perfectly Matched Layers)
- ionization and secondary emission (for studying multipacting/breakdown)

Important:
- VORPAL is 3D (also 2D and 1D), and is parallel

John Cary, Tech-X

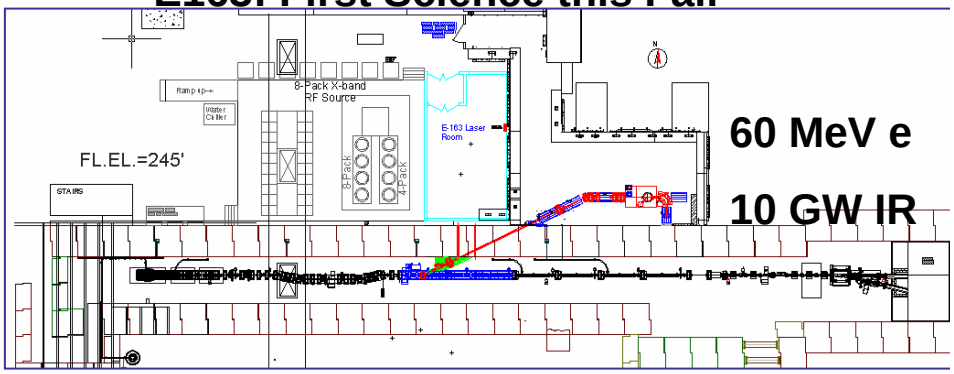
Reports on Technical Issues: Developing Beam Test Experiments



LACARA

Sergey Shchelkunoff, Columbia University

E163: First Science this Fall



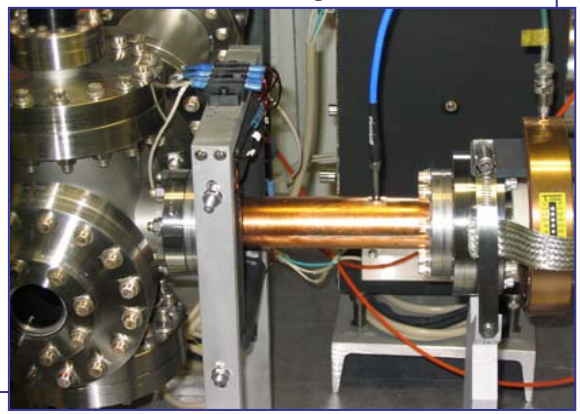
60 MeV e

10 GW IR

Eric Colby, SLAC

The maximum accelerating gradients achieved in the dielectric loaded structures at the **AWA Facility** have been steadily increasing:

- Summer 2005: 23 MV/m
- Winter 05/06: 43 MV/m
- Summer 2006: 86 MV/m



Manoel Conde, ANL

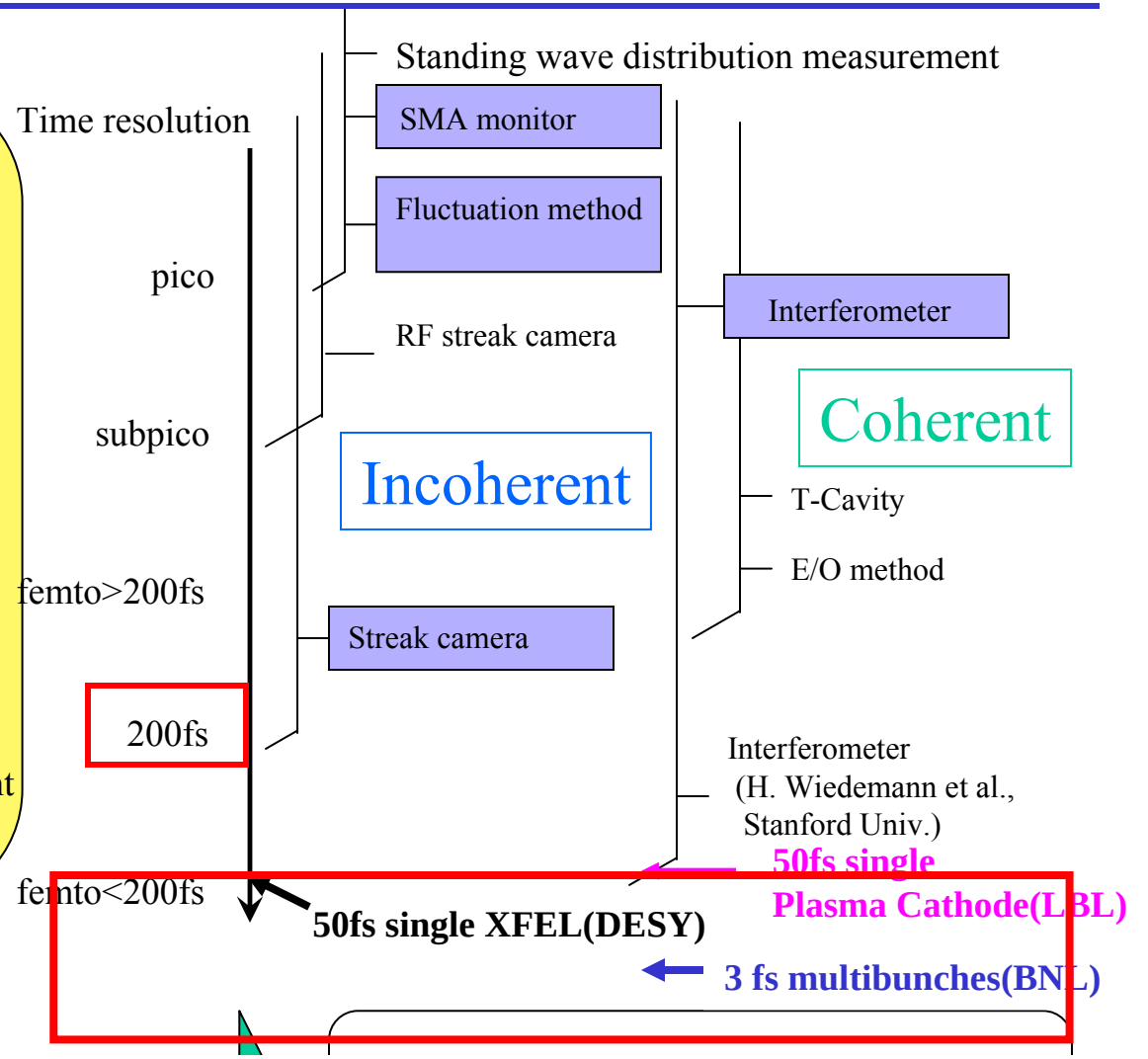
Methodology and Resolution of Pulse Length Measurement

Bunch length measurement method

○ Radiation techniques
- Streak camera
- Interferometer
- Fluctuation method

○ RF techniques
- Zero-Phasing method
- RF streak camera
- T-Cavity

○ Electric field of electron techniques
- SMA monitor
- Standing wave distribution measurement
- E/O method

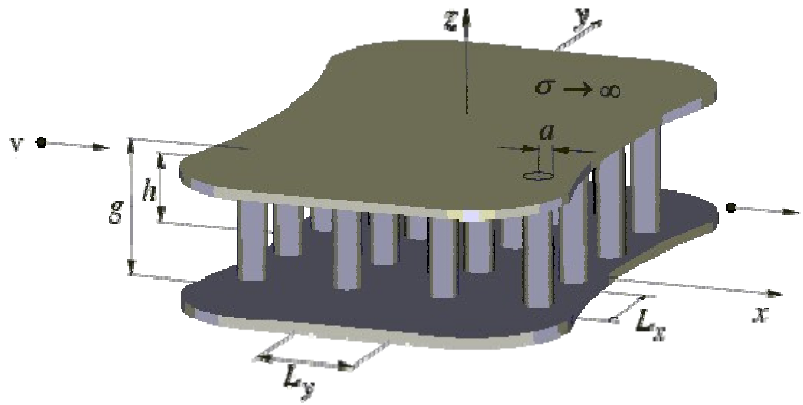


○ Radiation techniques
- Streak camera
- Interferometer
- Fluctuation method

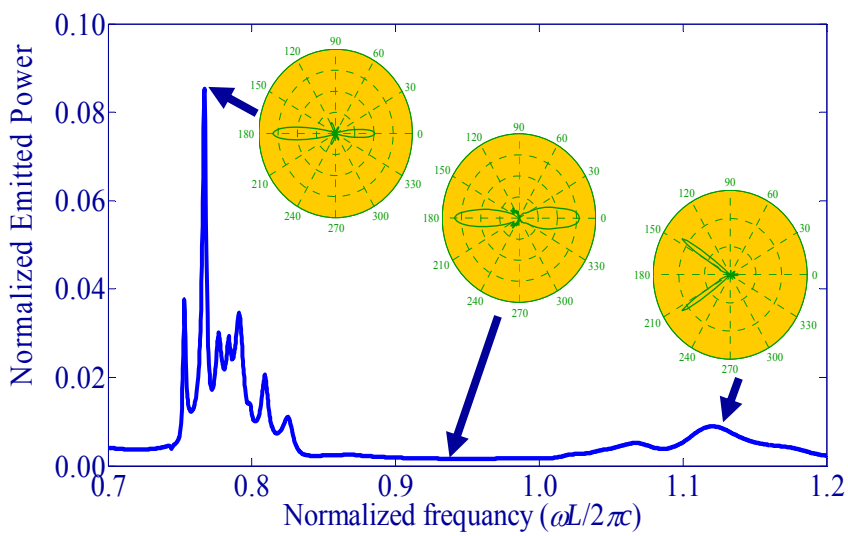
CR- and EO-techniques has realized ~50fs resolution

Mitsuru Uesaka, University of Tokyo

Metallic Post Array BPM
Samer Banna, Technion



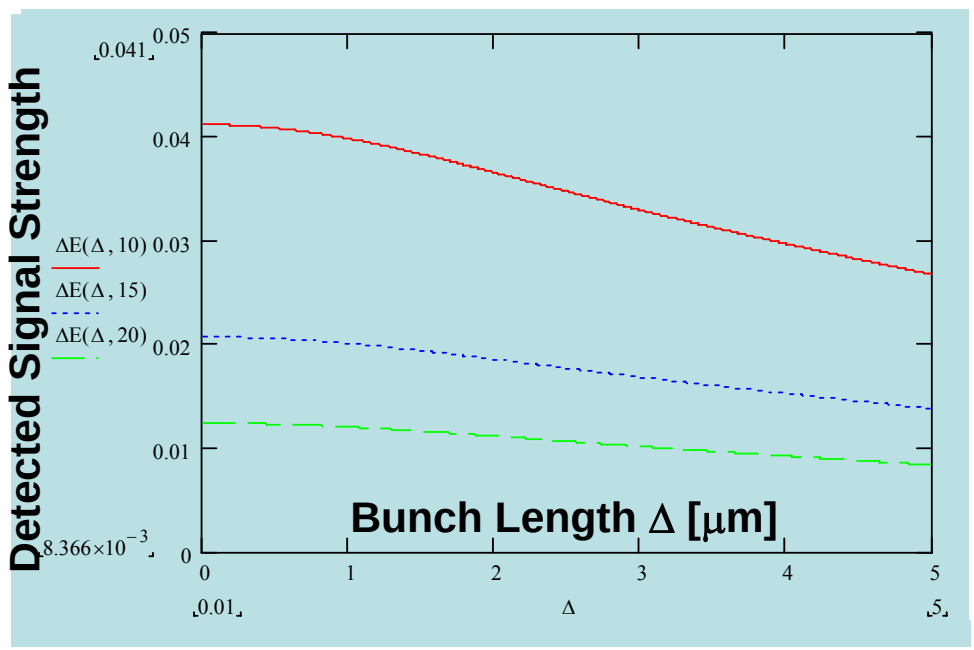
Periodic array of metal posts acts as a set of coherent dipole radiators, emitting **backward** radiation signature proportional to beam position. Resolutions of **few nm** potentially possible with room temperature photodiode detection.



Gas Resonance Bunch Length Detection
Levi Schächter, Technion

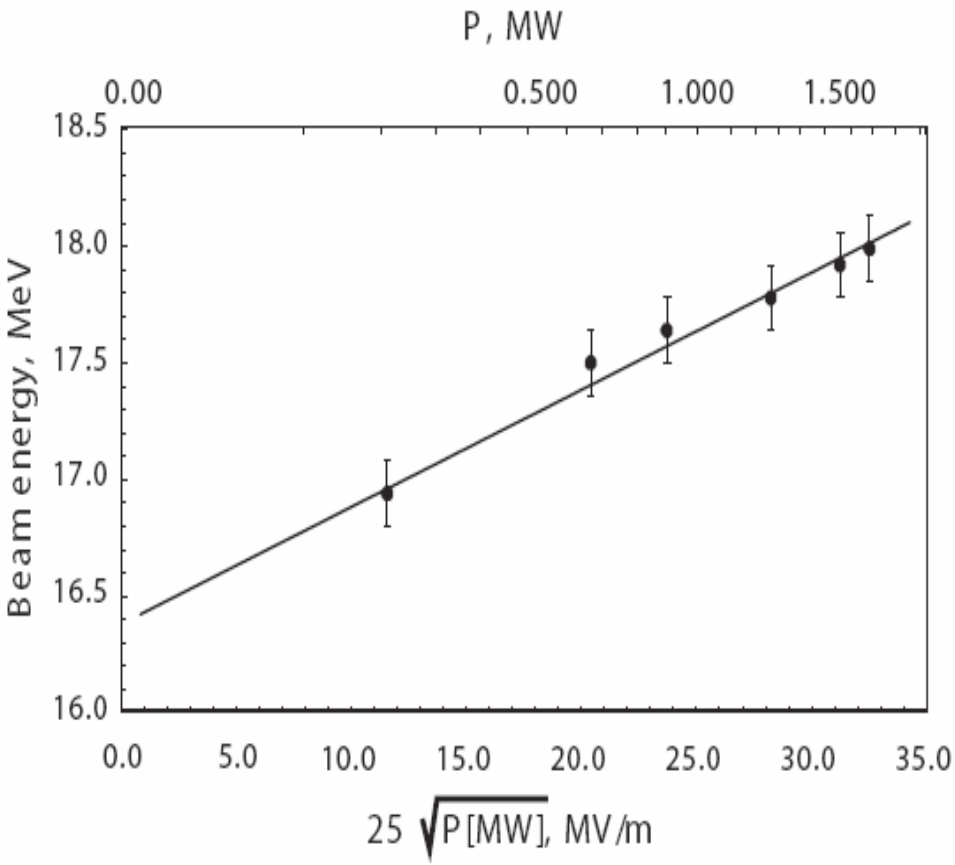
Very short bunches stimulate IR or optical emission from gas molecules in proportion to the high-frequency Fourier content of the bunch current.

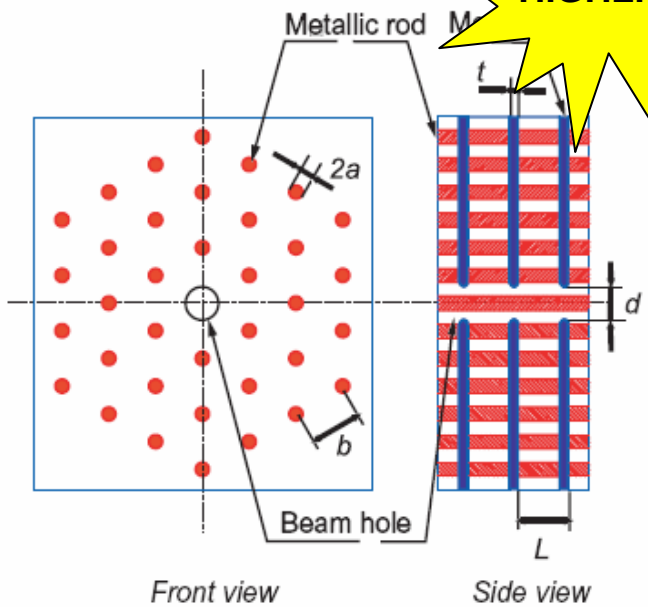
$$\overline{\Delta E} \sim \sum_{\nu} f_{\nu} \operatorname{sinc}^2\left(\frac{1}{2}\frac{\omega_{0,\nu}}{c}\Delta\right) F_{\perp}\left(\frac{\omega_{0,\nu}}{c} R_b\right)$$



PBG Experiment Results

WG7 HIGHLIGHT





- **Measured gradient 35 MeV/m**

E. Smirnova et al. PRL, 95, 074801 (2005)

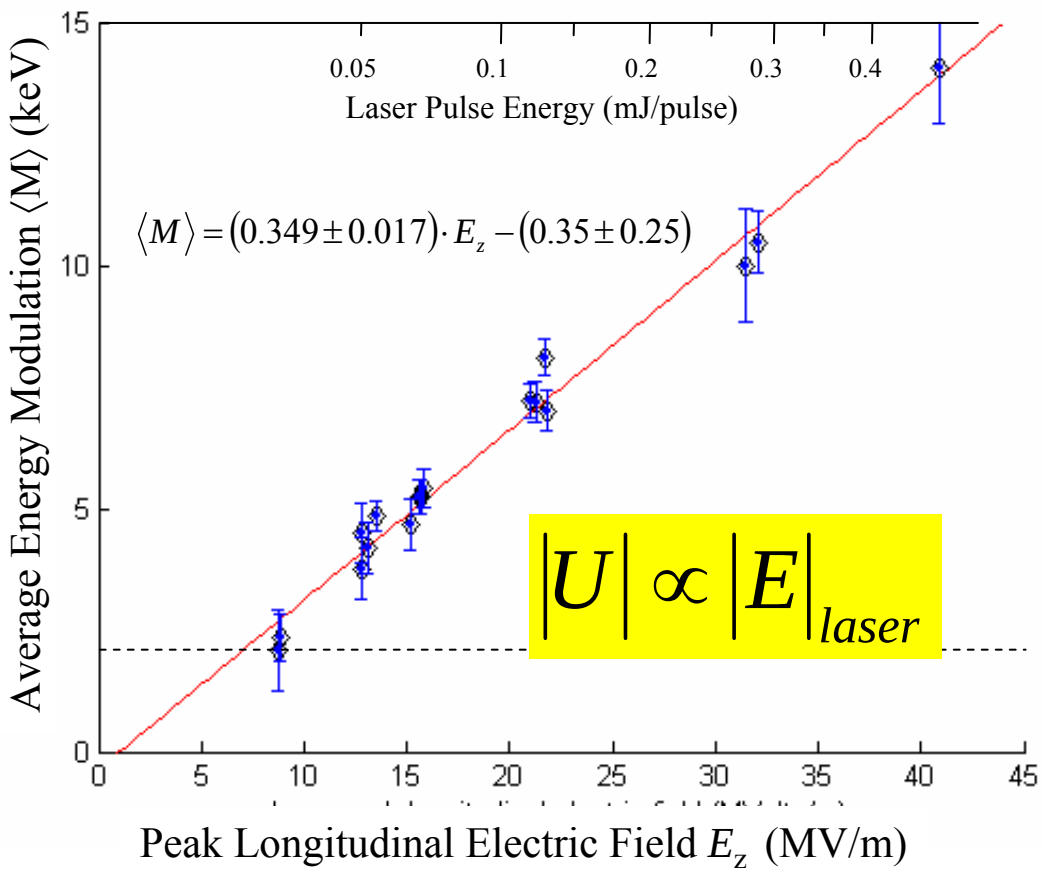
Presented by: Michael Shapiro, MIT

LEAP Demonstrates ITR and Harmonic IFEL at 0.8 μ

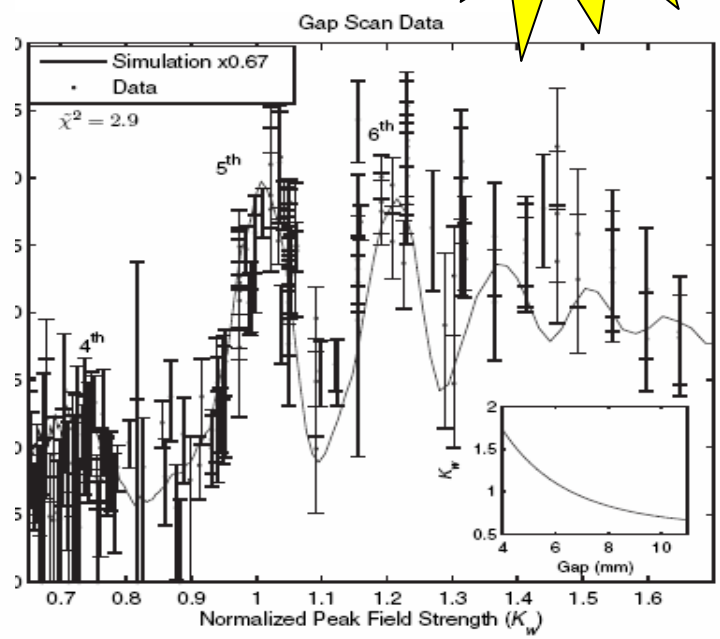
WG7 HIGHLIGHT

The dependence on the laser electric field amplitude

Average FWHM energy broadening



Observation of harmonic interaction



4. IFEL gap scan data, with 164 runs total. Comparison to lation (solid line) shows very good agreement to the shape spacing of resonance peaks. The harmonic numbers are ı next to each peak. Simulation has been rescaled vertically .67 to better visualize overlap.

Presented by: Tomas Plettner, Stanford University

AAC06

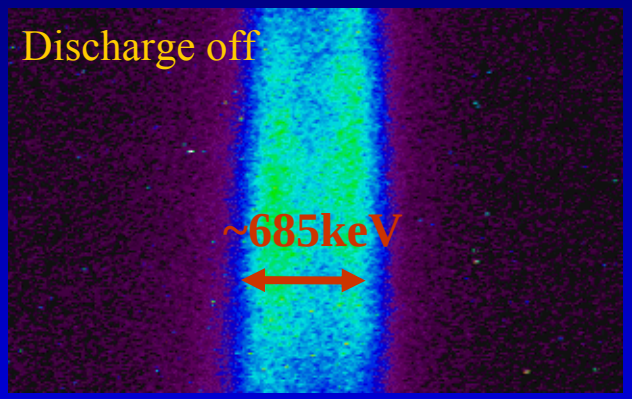
PASER Experimental Evidence

Brookhaven National Laboratory Accelerator Test Facility

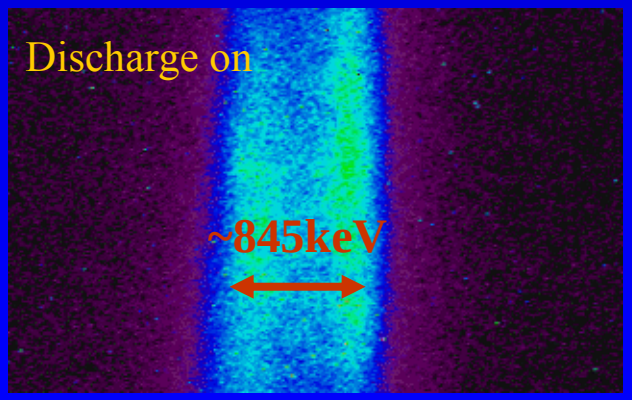
Technion Israel Institute of Technology

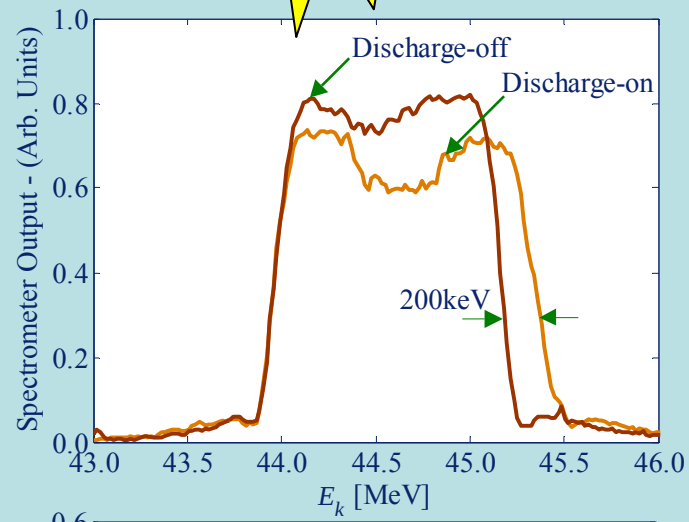
WG7 HIGHLIGHT

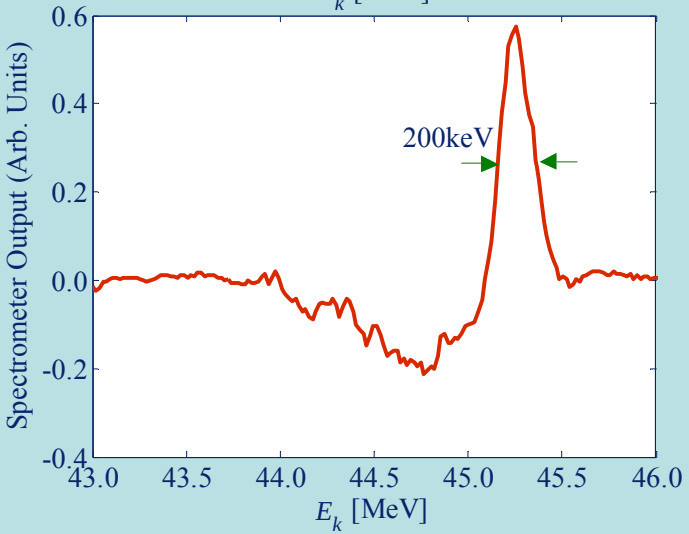
1.5% peak-to-peak energy modulation



Direction of increasing energy







Presented by: Samer Banna, Technion

Summary

(of the summary!)

Truly remarkable progress has been made since the 2004 AAC:

- Three first-of-kind demonstrations of new acceleration techniques:
  - Two demonstrated gradients exceeding present linac performance (PBG, ITR)
  - One demonstrating a technique unlike anything else (PASER)
- Two fundamental measurements of material damage strength, and plans for others:
  - Silicon, 1550 nm, 1 ps, equivalent to E_acc~0.25 GV/m
  - Silica, ~1 Thz, 1 ps, equivalent to E_acc~2 GV/m
  - Dielectric testing at 34 GHz at Yale/Columbia/Omega-P
- Technical advances in exotic material modeling (n<0, e<0) and preparation (diamond cylinders)
- Technical developments in coupling electron and radiation beams into structures, and using bunched beams for THz radiation generation, and much more.

Remarkable progress has been made– and plans for the future promise that the next AAC will be even more exciting.