Enabled by Echo

EEHG and More at NLCTA

Erik Hemsing
on behalf of the ECHO group
at SLAC NLCTA

ICFA Workshop on Future Light Sources
March 5-9, 2012
Thomas Jefferson National Accelerator Facility

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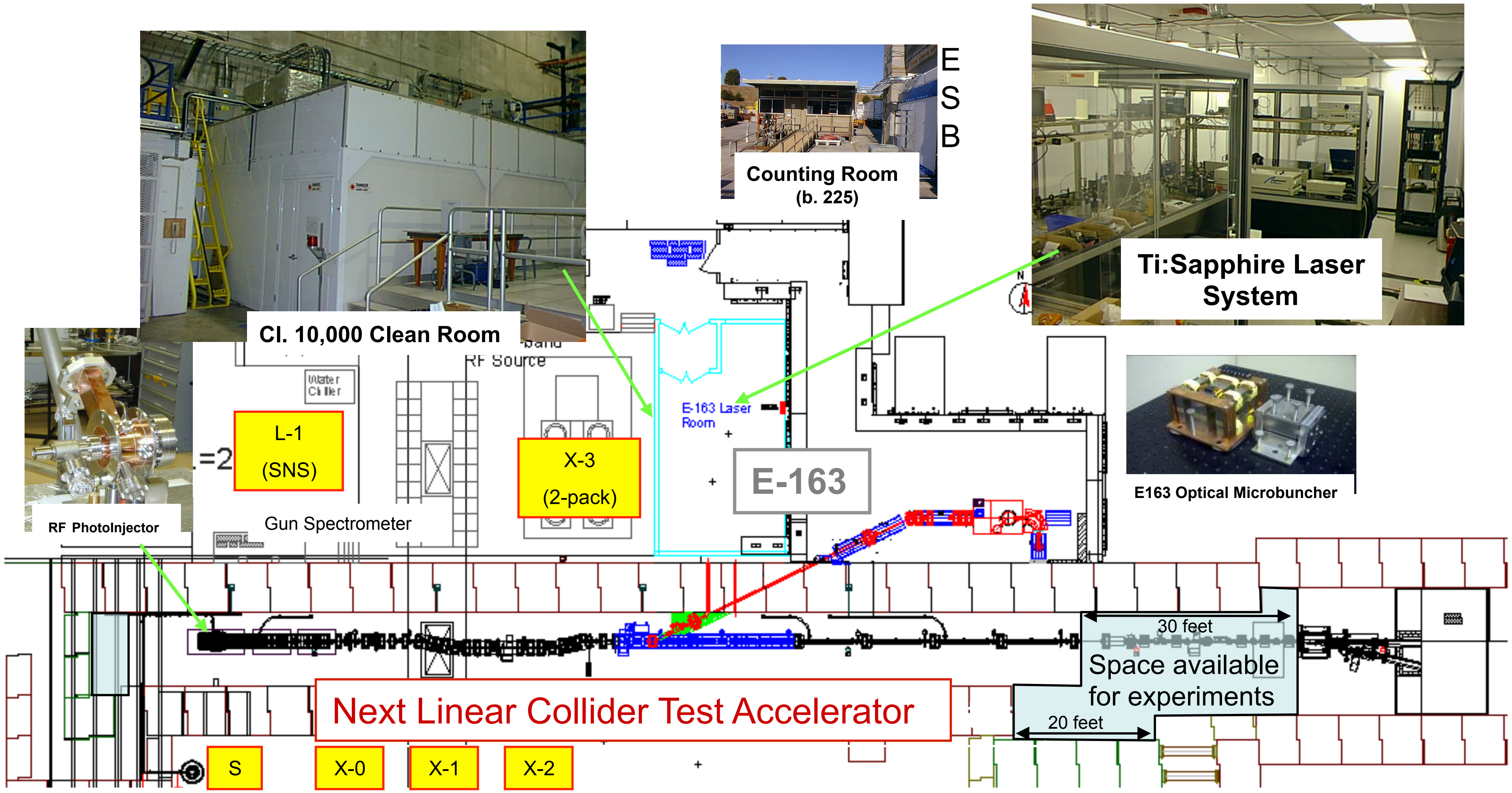
NLCTA Overview



NLCTA capabilities:

120 MeV beams (to ~300 pC)

* S-band Injector producing high-brightness ~~60 MeV beams (to ~100 pC)~~; ultrashort, ultracold
* (4) x-band rf stations and >300 MeV historically
* (2) L-band rf stations
* Skilled operations group with significant in-house controls capability

From E. Colby : https://slacportal.slac.stanford.edu/sites/ard_public/tfd/facilities/nlcta/Documents/NLCTAFacility%20Colby.ppt.

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NLCTA Capabilities

Electron beam

120 MeV, <300 pC, $\delta p/p \sim 3 \times 10^{-5}$, $\sigma_t \sim 0.5$ psec

Beamline & laser pulse optimized for very low energy spread, short pulse operation

Laser Beams

10 GW-class Ti:Sapphire system (800nm, 2 mJ)

KDP/BBO Tripler for photocathode (266nm, 0.16 mJ)

Active and passive stabilization techniques

5 GW-class Ti:Sapphire system (800nm, 1 mJ)

100 MW-class OPA (1000-3000 nm, 80-20 μJ)

5 MW-class DFG-OPA (3000-10,000 nm, 1-3 μJ)

Precision Diagnostics

Picosecond-class direct timing diagnostics

Micron-resolution beam diagnostics

Femtosecond-class indirect timing diagnostics

THz Bolometer/ BLIS

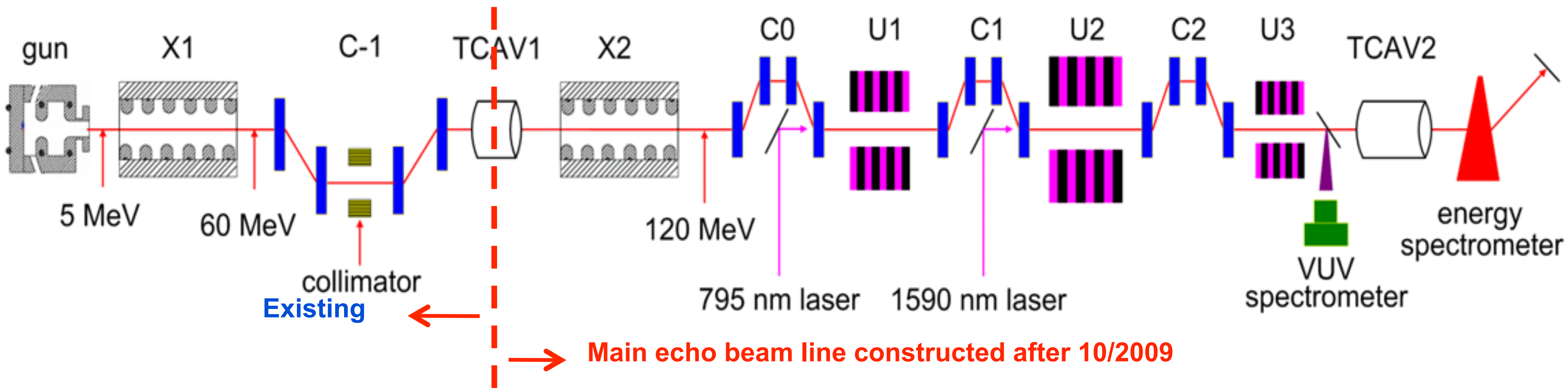
FROG

Picocoulomb-class beam diagnostics

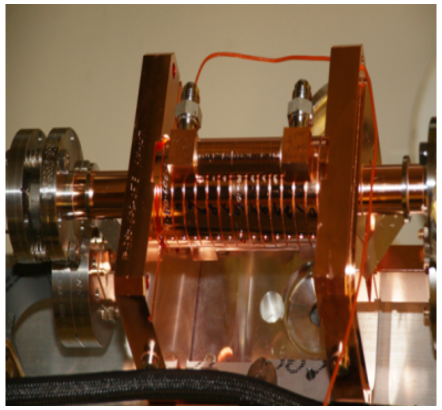
BPMS, Profile screens, Spectrometer

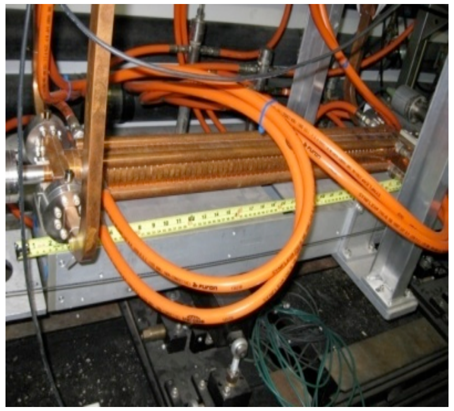
A range of laser diagnostics, including autocorrelators, crosscorrelators, profilometers, etc.

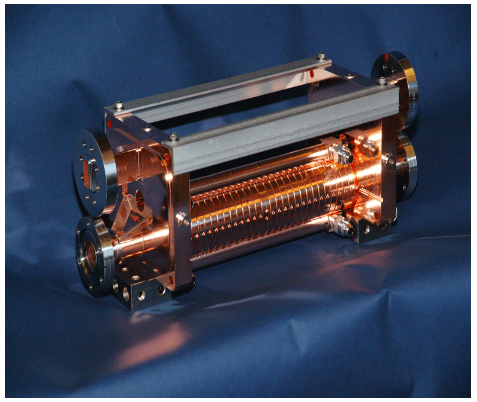
Existing Echo experiment at NLCTA

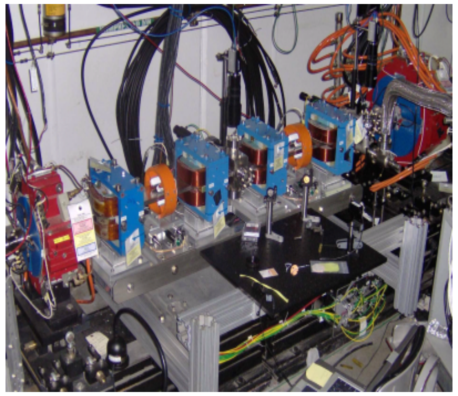


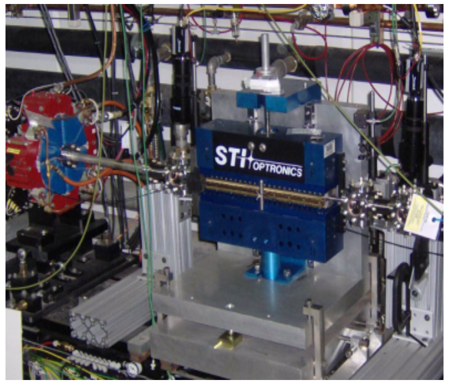

C-1


TCAV1

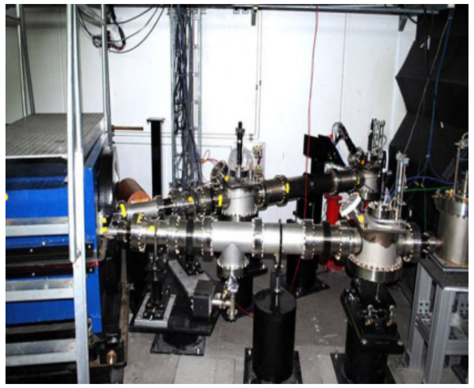

X2


TCAV2


C1


U1

U2

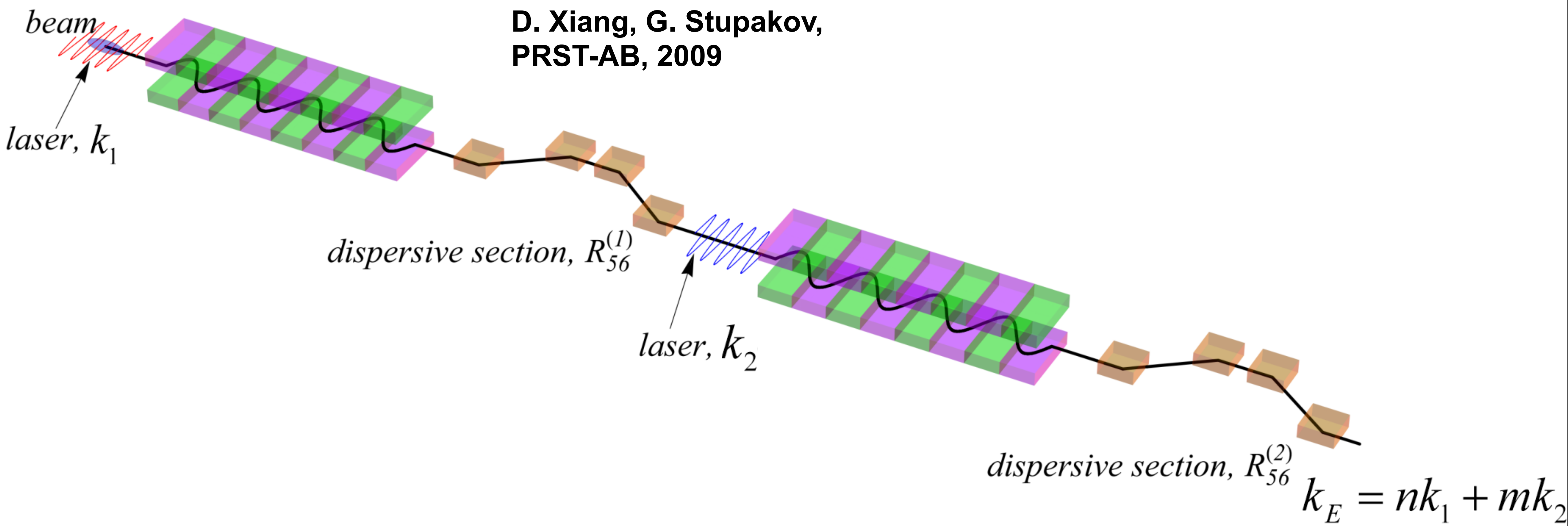

spectrometer

(Courtesy of D. Xiang)

Echo-Enabled Harmonic Generation (EEHG)

G. Stupakov, PRL, 2009;

D. Xiang, G. Stupakov, PRST-AB, 2009



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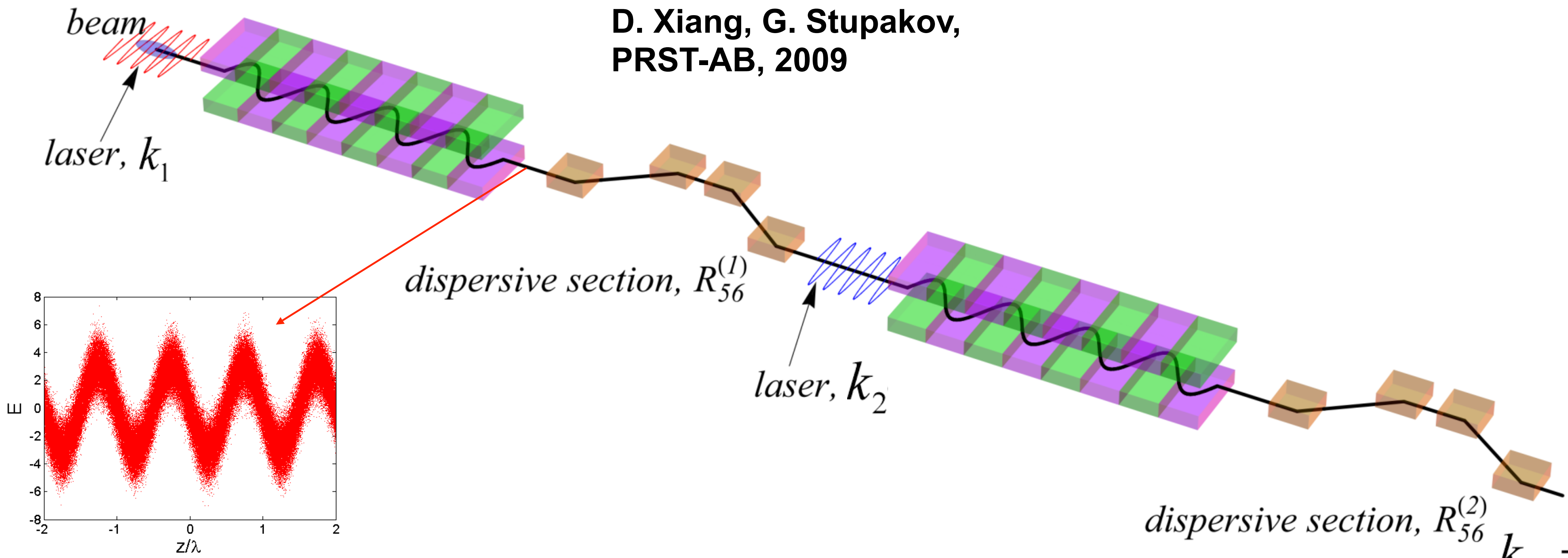

$$k_E = nk_1 + mk_2$$

- First laser generates energy modulation in electron beam

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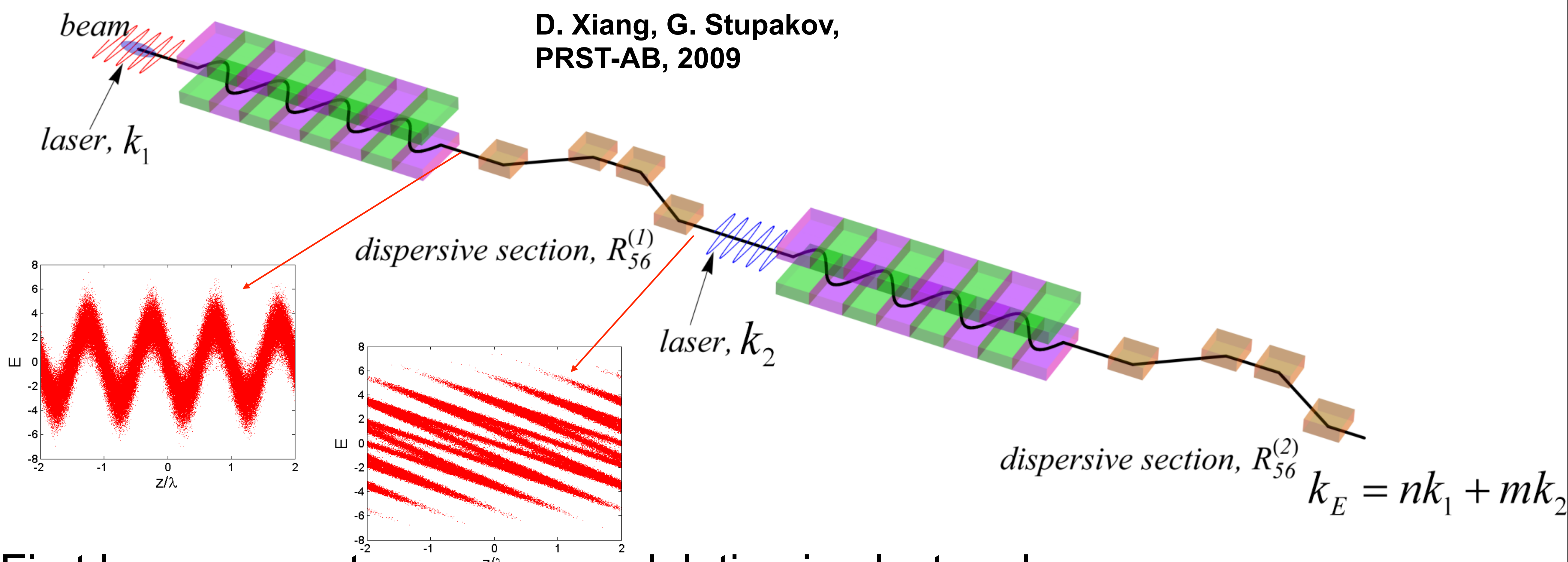

- First laser generates energy modulation in electron beam
- First strong chicane stratifies the longitudinal phase space

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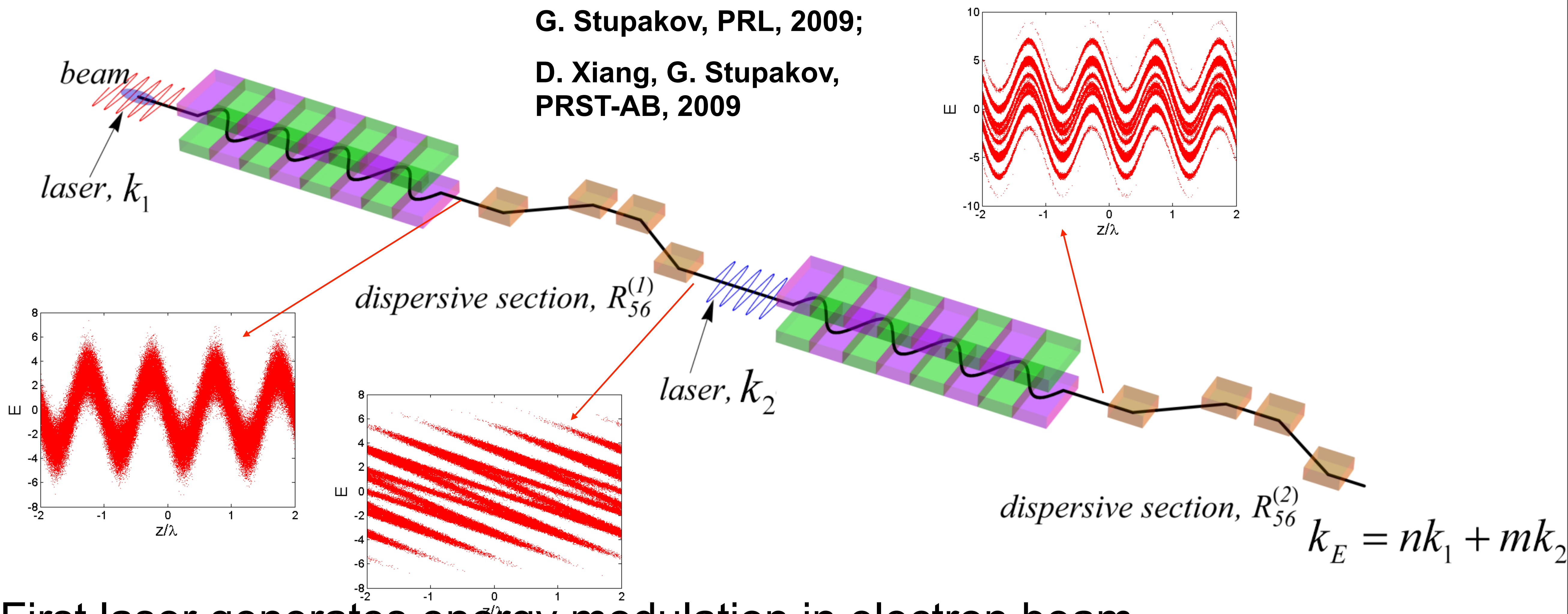

- First laser generates energy modulation in electron beam
- First strong chicane stratifies the longitudinal phase space
- Second laser imprints energy modulation

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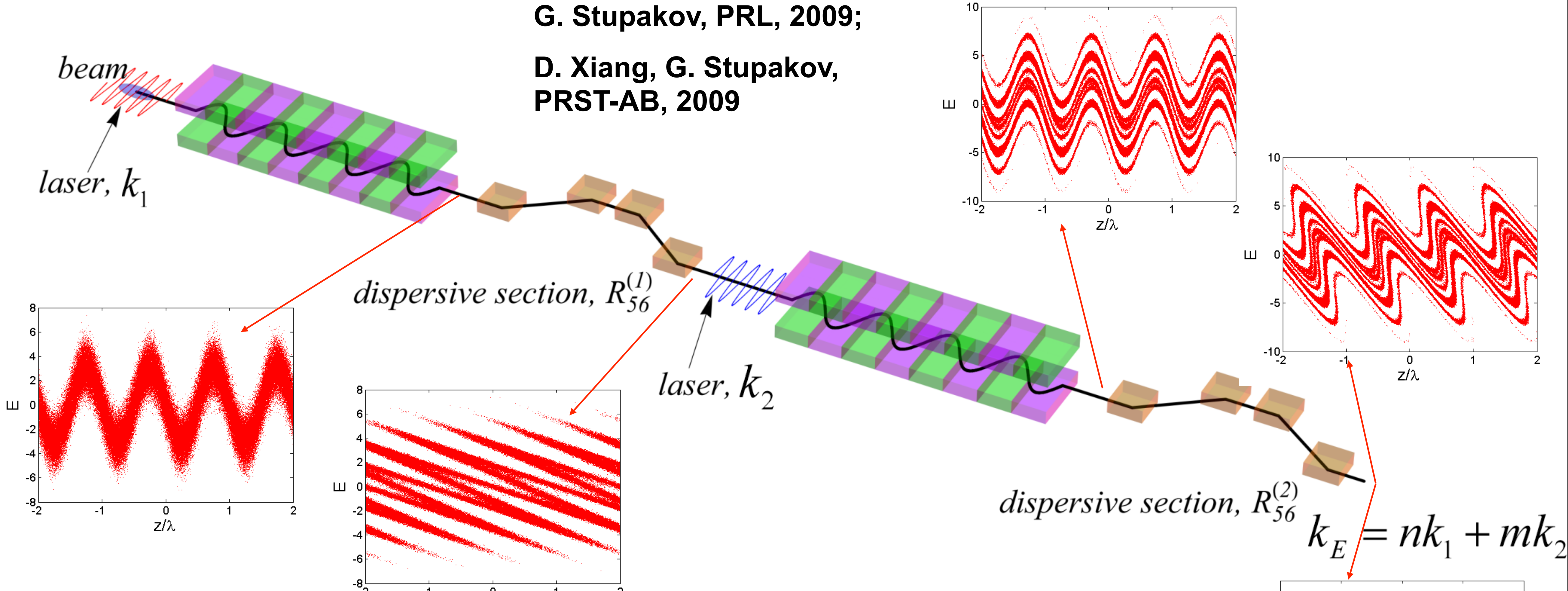

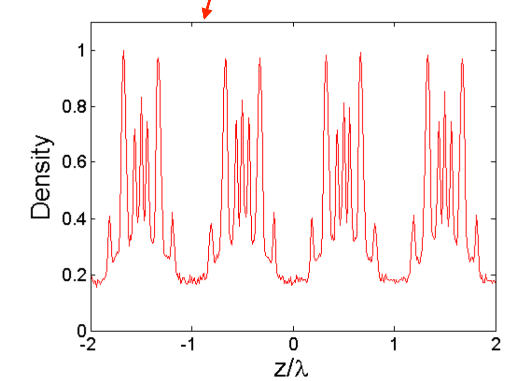

- First laser generates energy modulation in electron beam
- First strong chicane stratifies the longitudinal phase space
- Second laser imprints energy modulation
- Second chicane converts energy modulation into harmonic density modulation

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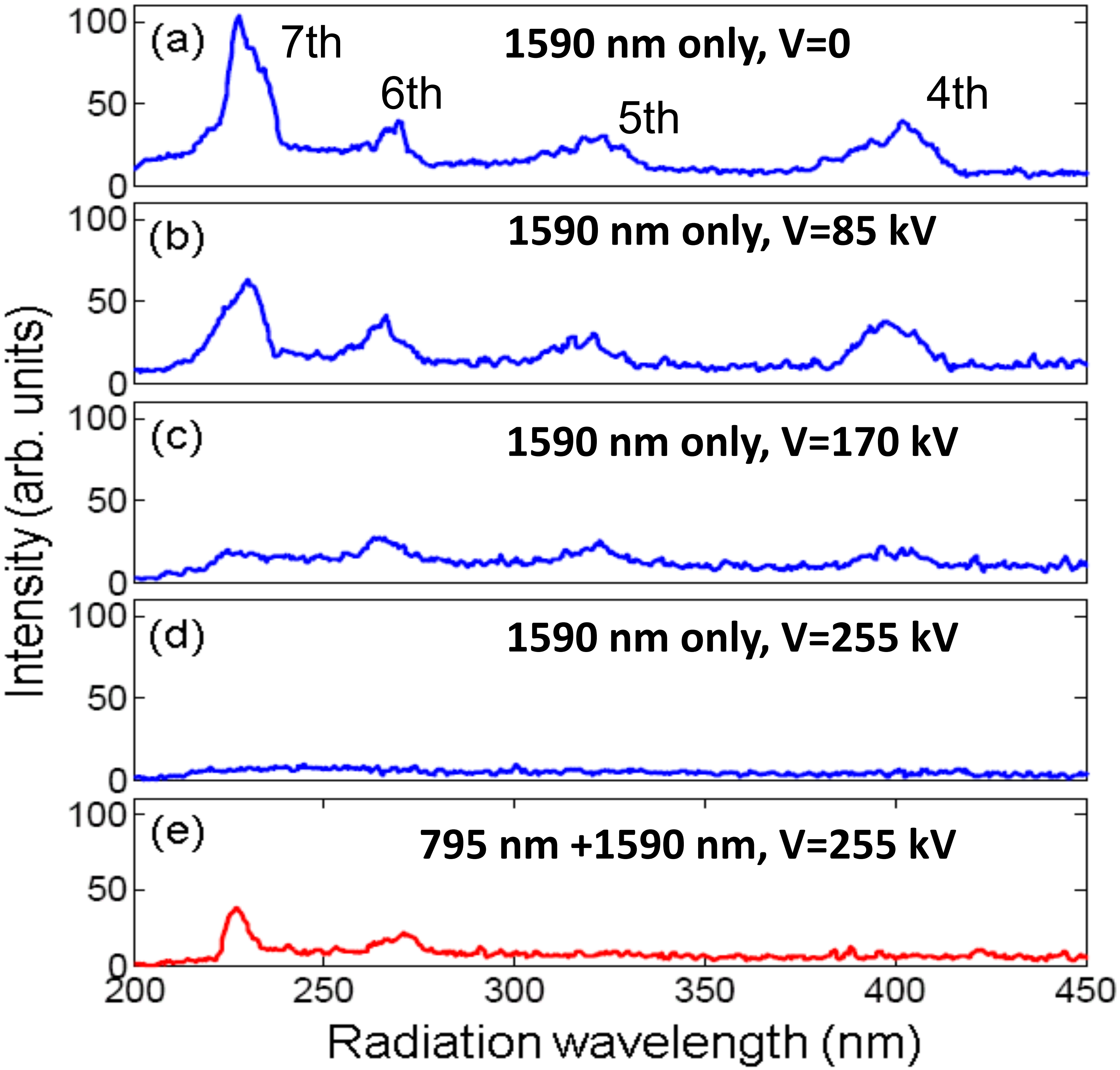
(Courtesy of D. Xiang)

ECHO-7 (2011) $k_E = -2k_1 + 11k_2 = 7k_2$



- **4th to 7th harmonics from HGHG suppressed with increased beam slice energy spread from TCAV**
- **7th harmonic reappears with the first laser on, like an echo**
- **7th harmonic generated when energy modulation is about 2~3 times the beam slice energy spread**

- D. Xiang, et al, **PRL 108, 024802 (2012).**

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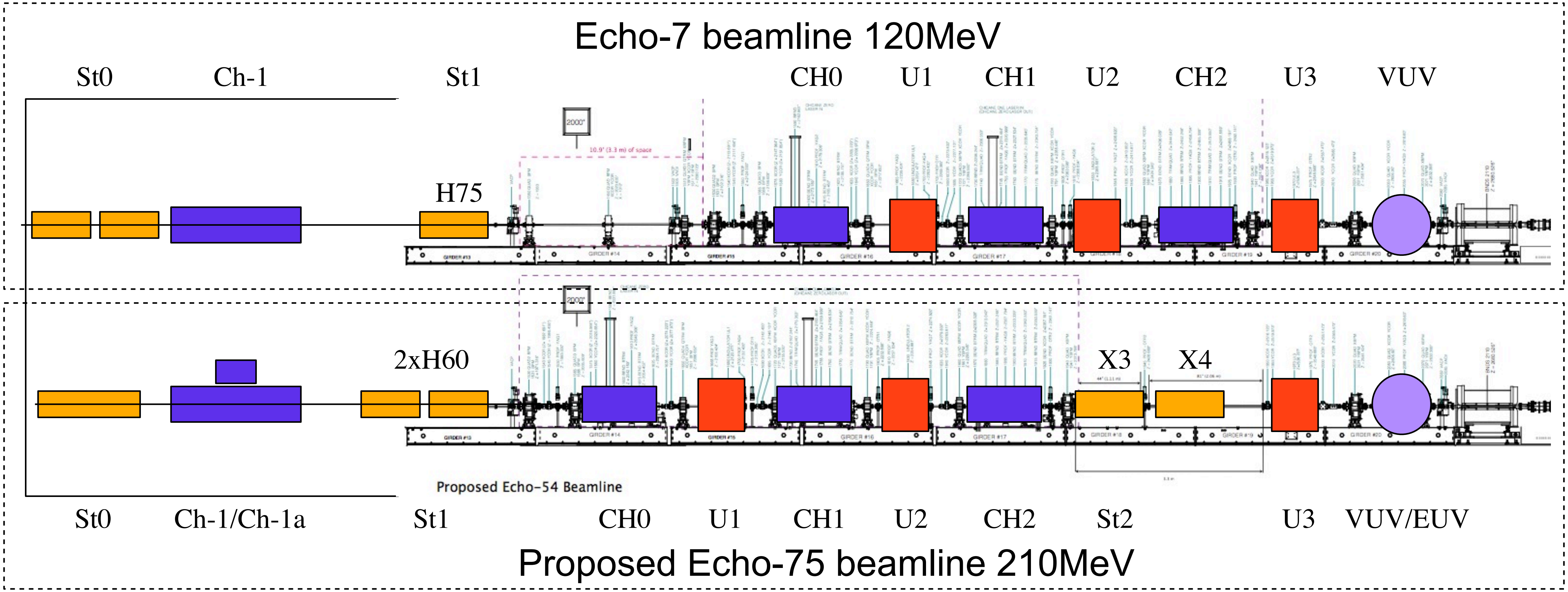
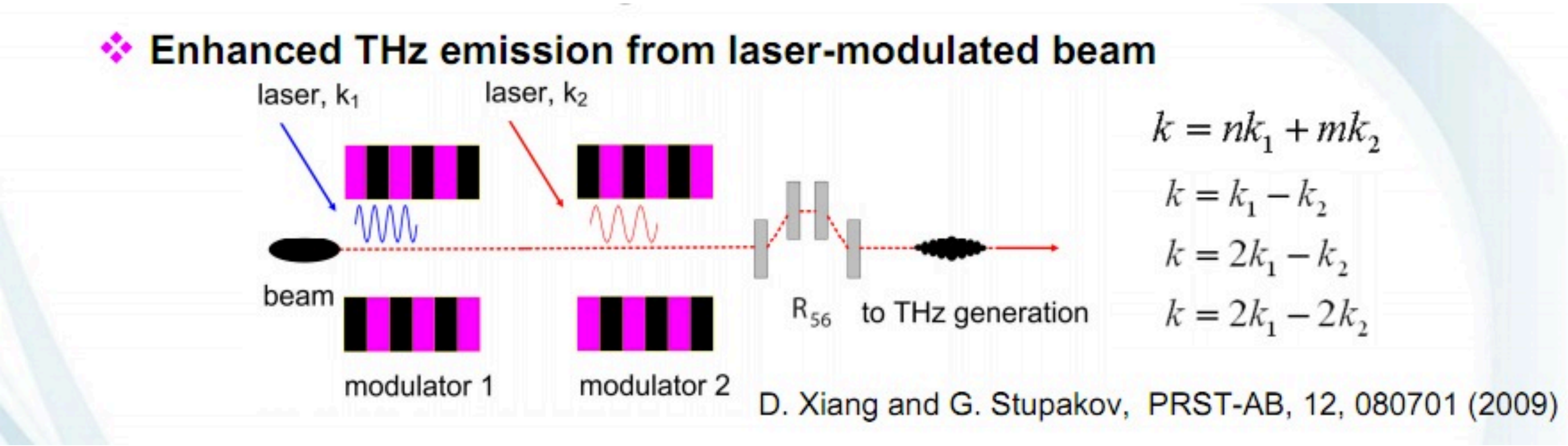
2012+ NLCTA Outlook

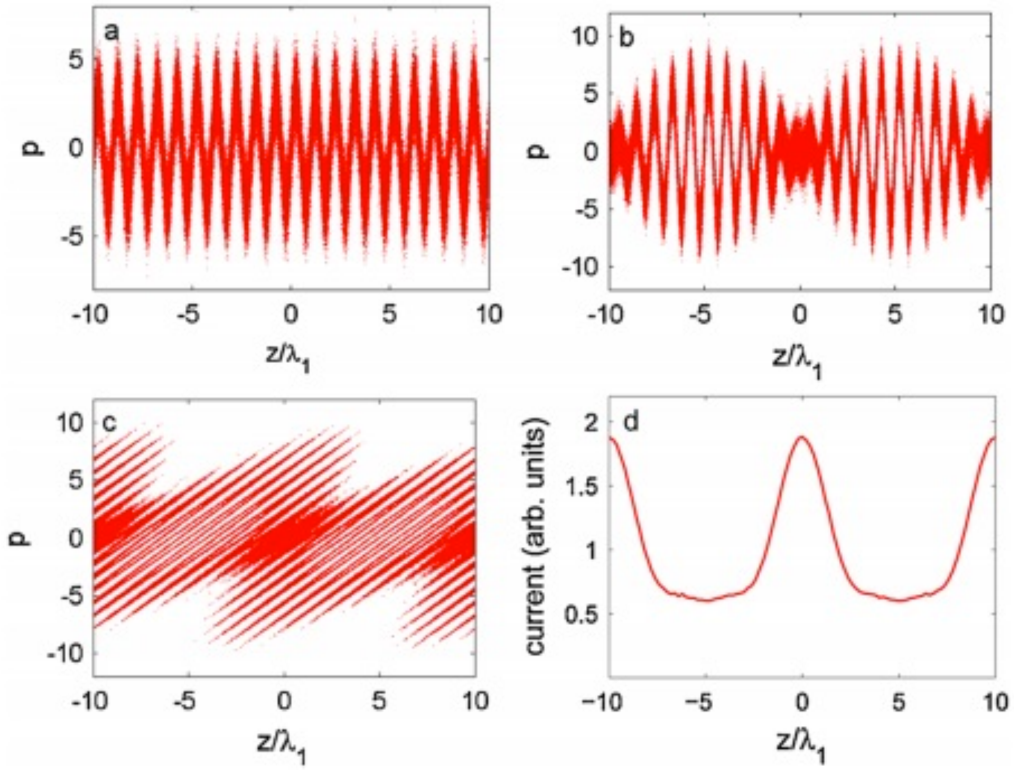
- Plan: utilize versatility of EEHG infrastructure for assorted, dedicated high-brightness e-beam R&D
- Goal: transition to new ECHO-X (X=11, 21, 32, 75...) program, performing several key experiments and upgrades enroute.



Seeding/Beam Manipulation

Tunable, narrowband THz





Seeding/Beam Manipulation

Optical sampling of phase space

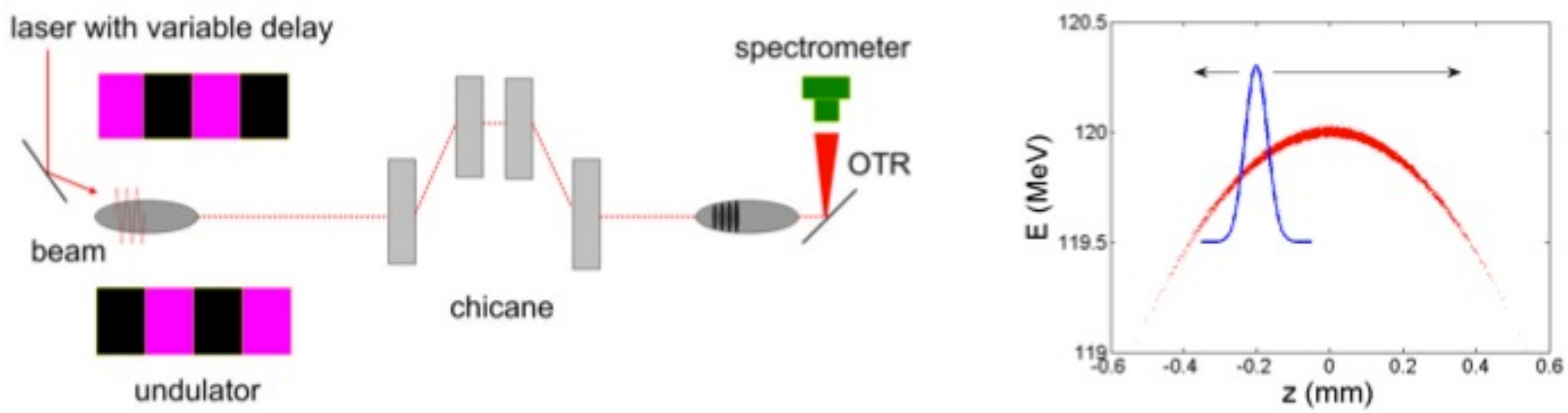


Fig. 1 Schematic of phase space characterization with electron-laser interaction.

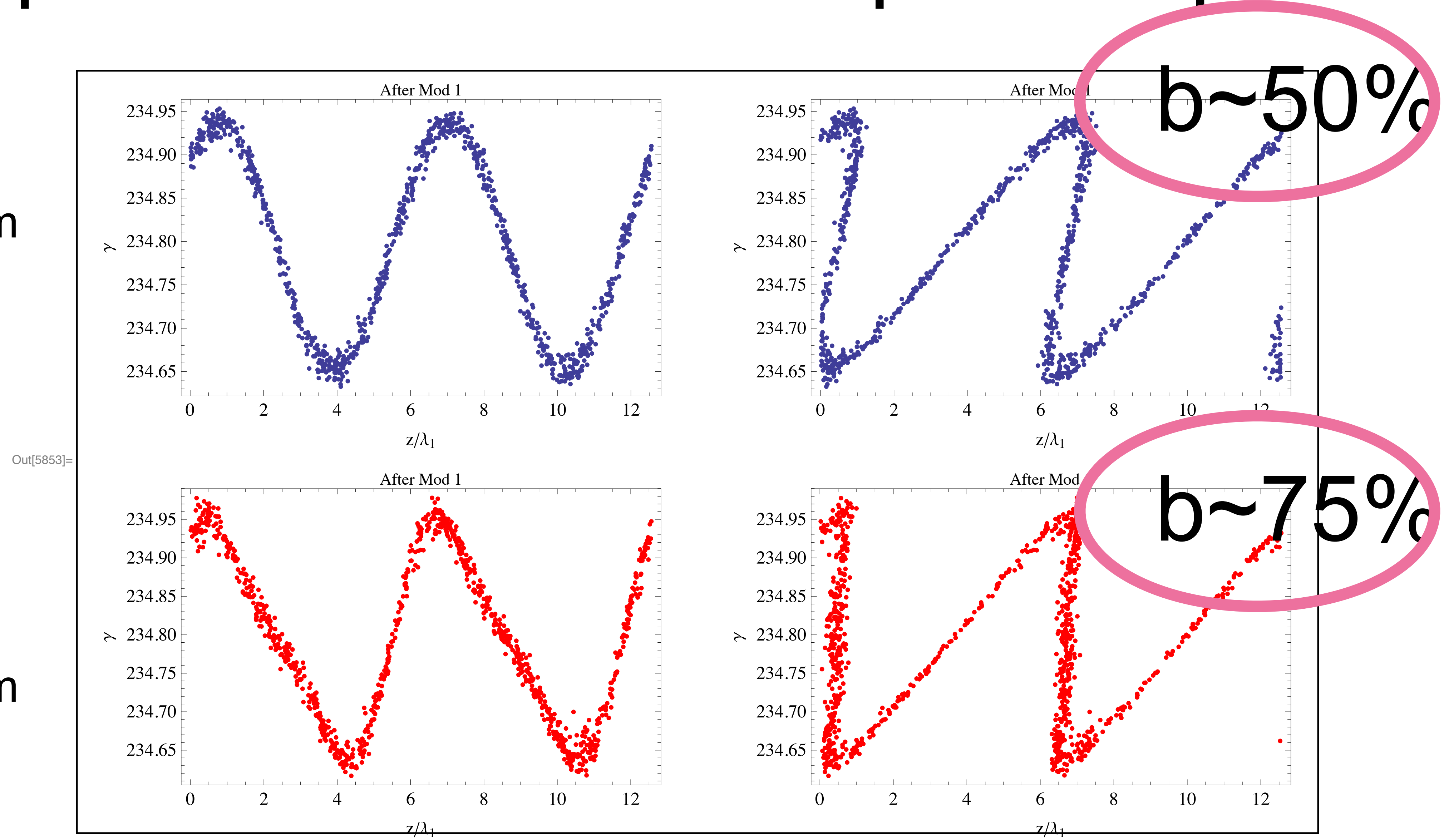
- Short laser pulse modulates portion of e-beam in U1.
- R56 generates density modulation, shifted from laser wavelength according to local chirp h by 1+hR56
- CTR power and spectra give beam current and chirp information as a function of delay.
- Compare with TCAV & energy spectrometer

Seeding/Beam Manipulation

Optical linearization of phase space

1600 nm only

800+ 1600 nm



Best case is when amplitude of 1600nm is 2.2 amplitude of 800nm, and phase diff =0

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Advanced Technologies

High Efficiency Cryogenic Wiggler

- Demonstration of short-period, high field cryoundulator technology for efficient coupling

FIG. 7: CPMU-9

TABLE I: The parameters of CPMU-9

Period length	9 mm
Num of periods	20
Bmax (30K)	1.2 T
K (30K)	1
Gap	2.5 mm
Length	20 cm

TABLE II: Parameters used in the Genesis simulations of microbunching.

Beam Energy	47 MeV
Sl. En. Spread	1 keV
Norm. Emit.	8 mm mrad
Current	250 A (25pC/1ps)
Laser λ	795 nm
Laser Power	15 MW

F. O'Shea - UCLA

Advanced Technologies

Xband RF Undulator

Shumail, et al. Proceedings of IPAC2011, San Sebastián, Spain

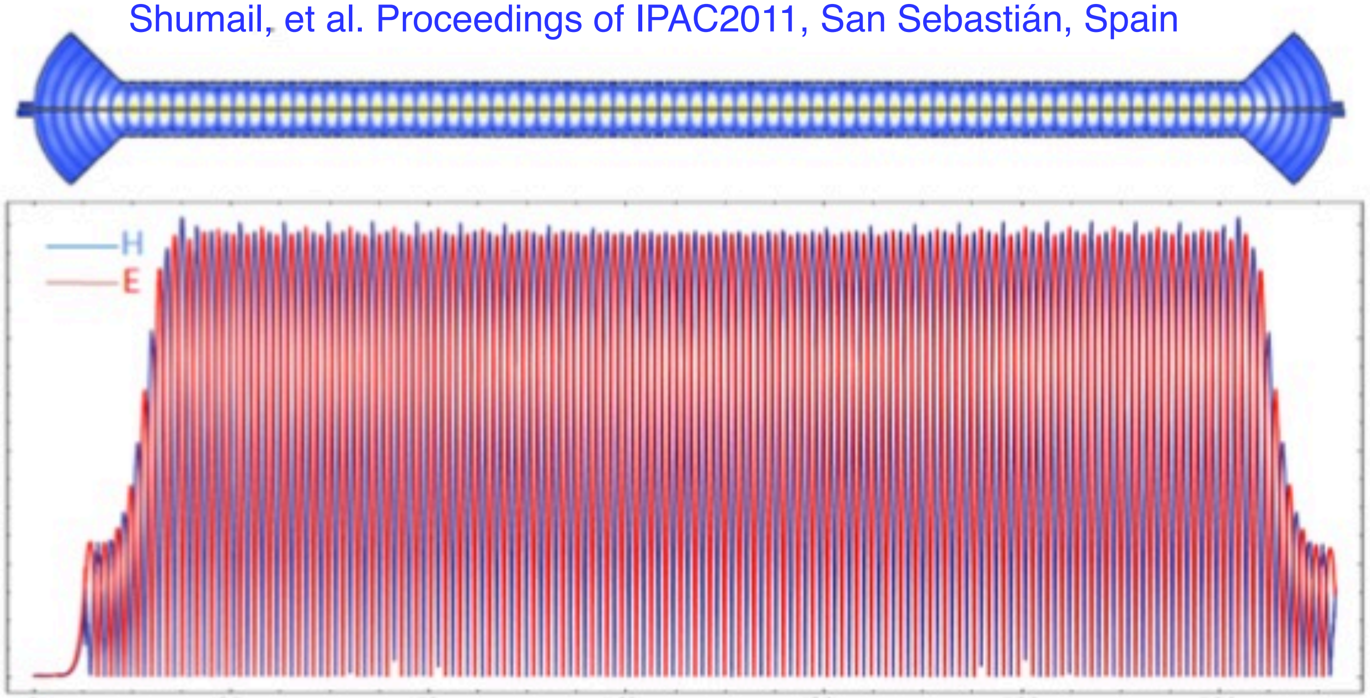


Figure 3: An optimized design of RF undulator and fields along its axis.

1m (~100 periods)

- 50 MW of input power gives large fields (K~1) at short wavelengths (~1cm)
- Highly tunable K, adjustable polarization

Experimental Testing of an X-band RF Undulator at NLCTA

I. Undulator Parameters

1. Physical Length: 54.411” (**1.38 m**)
2. Power requirements : 50 MW
3. Pulse length: 1.5 us (filling time ~ 600 ns)
4. 2 WR90 inputs. With hybrid, no reflection to the klystron and helically polarized mode (K~0.71). Without the hybrid, linearly polarized wave (K~1) and will have an initial reflection to the klystron until filled.

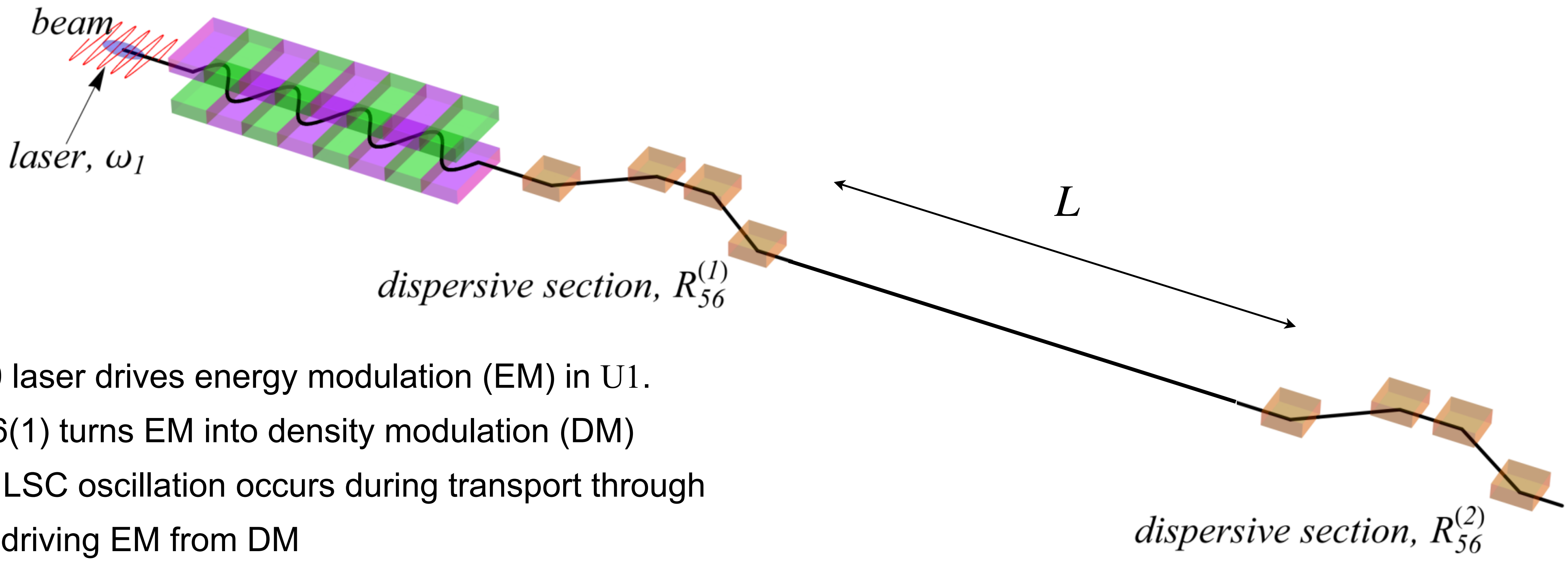
II. Testing requirements

1. Needs the full power of one klystron
2. Needs at least 60 MeV beam
3. Laser input for seeding at ~800 nm, and/or seeded by MB beam at 800 nm.
4. Would like to have a dipole before and/or after the device (“and” is preferable)
5. Slice emittance: of 2 microns
6. Charge/bunch 50 pc
7. peak current of 50 A after compression
8. Spectrometer that can go all the way to 200 nm or lower
9. Would prefer to be able to get a beam up to 120 MeV
10. Beam diagnostics (including TCAV if possible)

S. Tantawi et al, SLAC

Collective Effects

LSC Amplifier/Suppressor



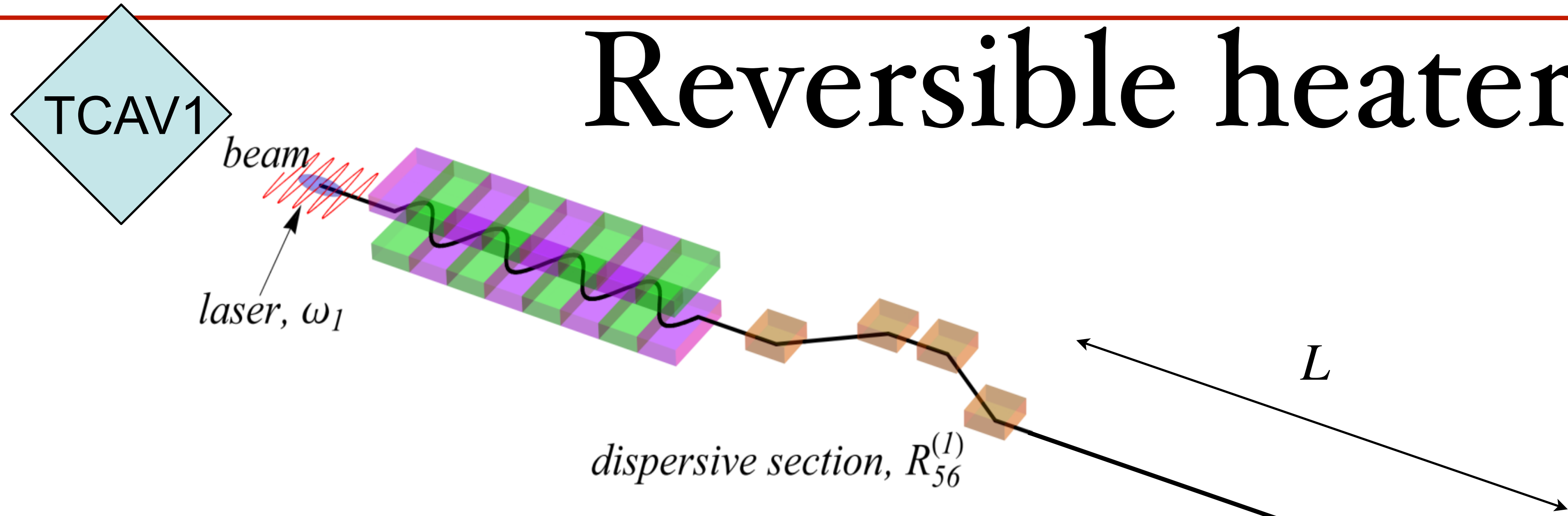
- 800 laser drives energy modulation (EM) in U1.
- R56(1) turns EM into density modulation (DM)
- 1/4 LSC oscillation occurs during transport through drift, driving EM from DM
- R56(2) transfers EM generated by LSC back to DM, but amplified

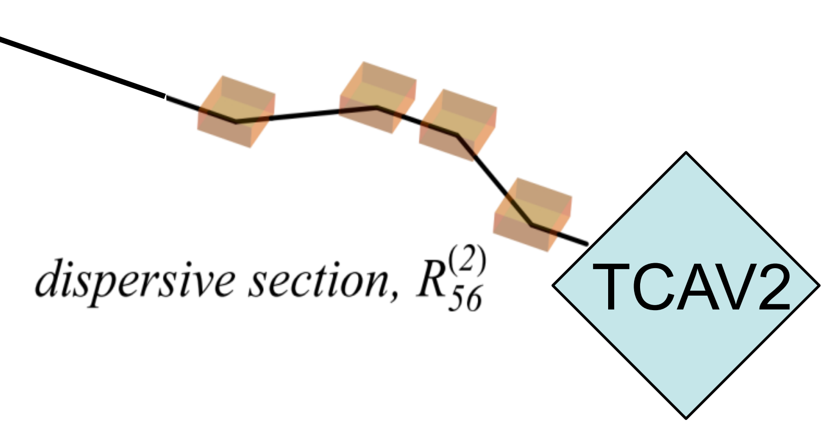
$$\frac{b_{R_{56}}}{b_0} = \gamma^2 k R_{56} e^{-\frac{(k\sigma_\eta R_{56})^2}{2}} \sin kL$$

A. Marinelli - UCLA

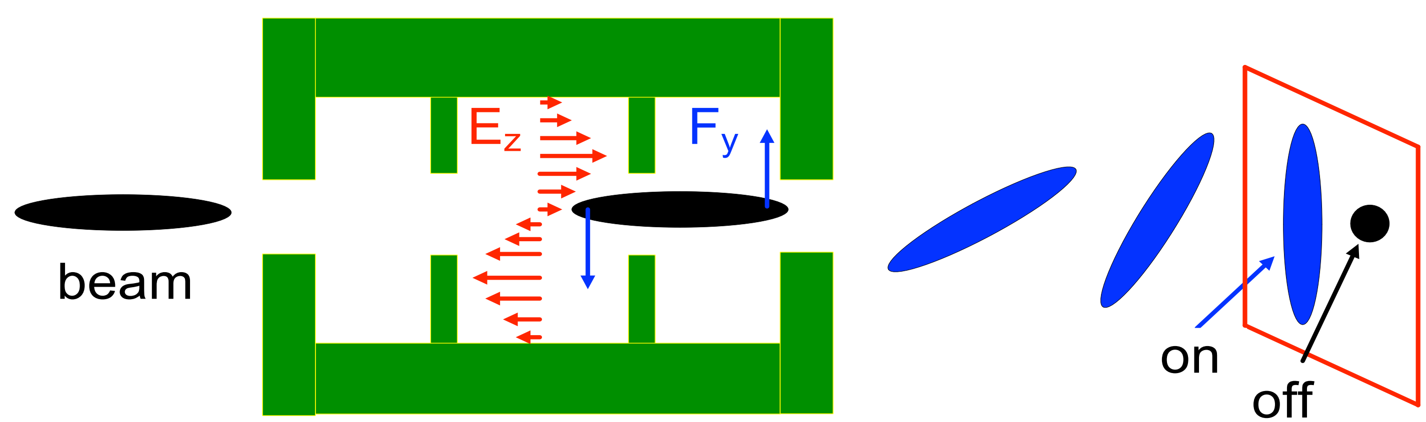
Collective Effects

Reversible heater





- Typically a 'laser heater' is used to increase beam slice energy spread to damp instabilities
- RF transverse cavity used to increase slice energy spread to damp collective instabilities, but correlation is preserved in transport and removed downstream



$$\delta = k\sigma_x \qquad k = \frac{2\pi eV}{\lambda_{RF} E}$$

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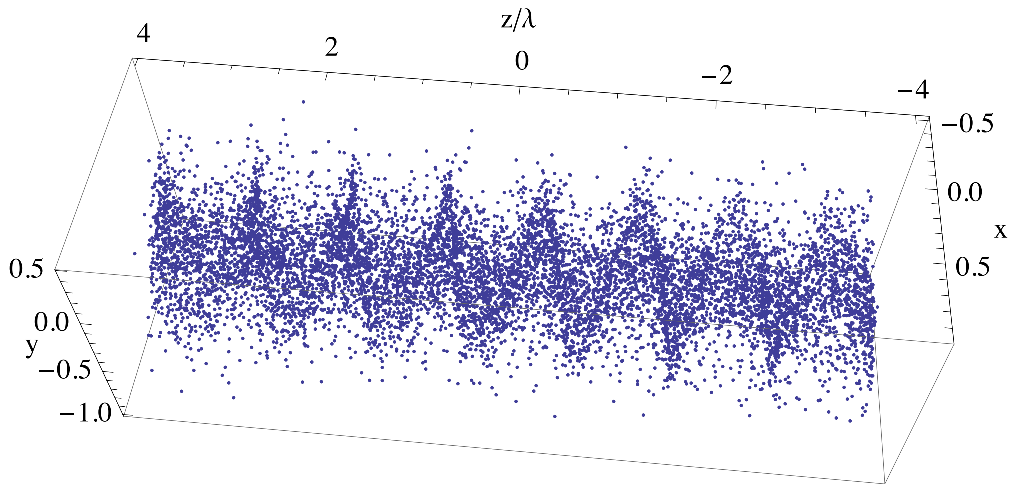
Reversible heater: C. Behrens, Z. Huang and D. Xiang, PRSTAB 15, 022802 (2012)

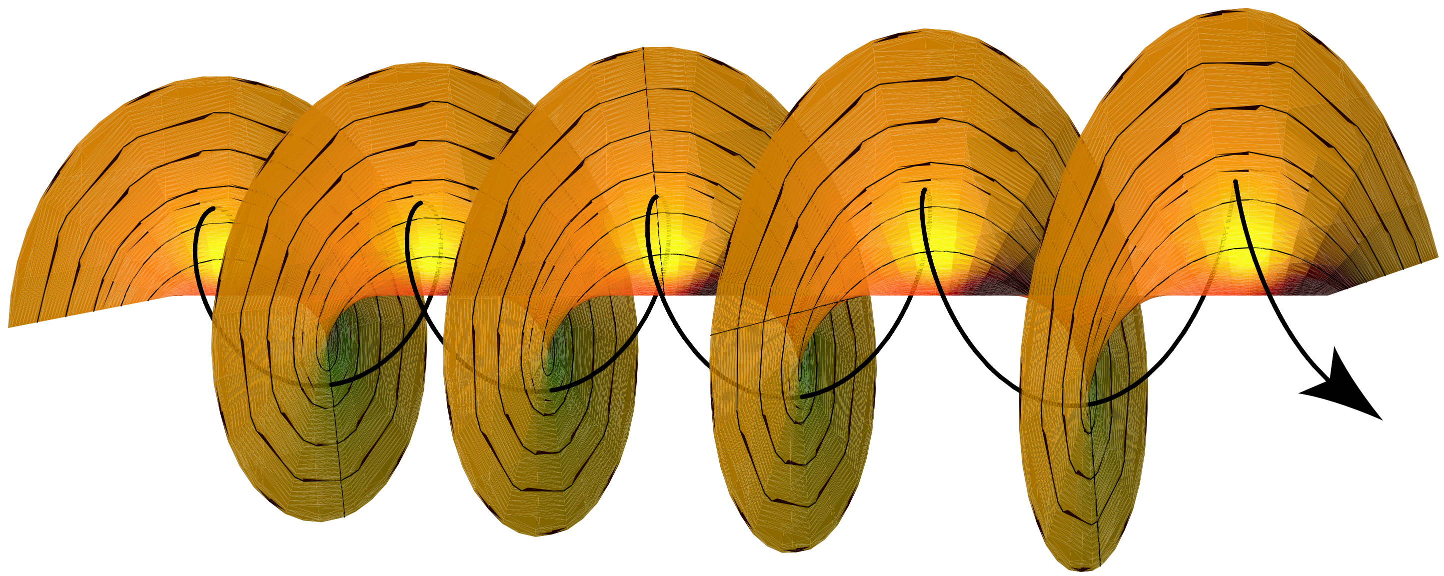
Higher Order Interactions

Optical OAM generation

Demonstrate the generation of optical vortices in optical klystron.

Principle:
Helical e-beam microbunching leads to emission of light with helical phase fronts





EH, et al. PRL 106, 164803 (2011)

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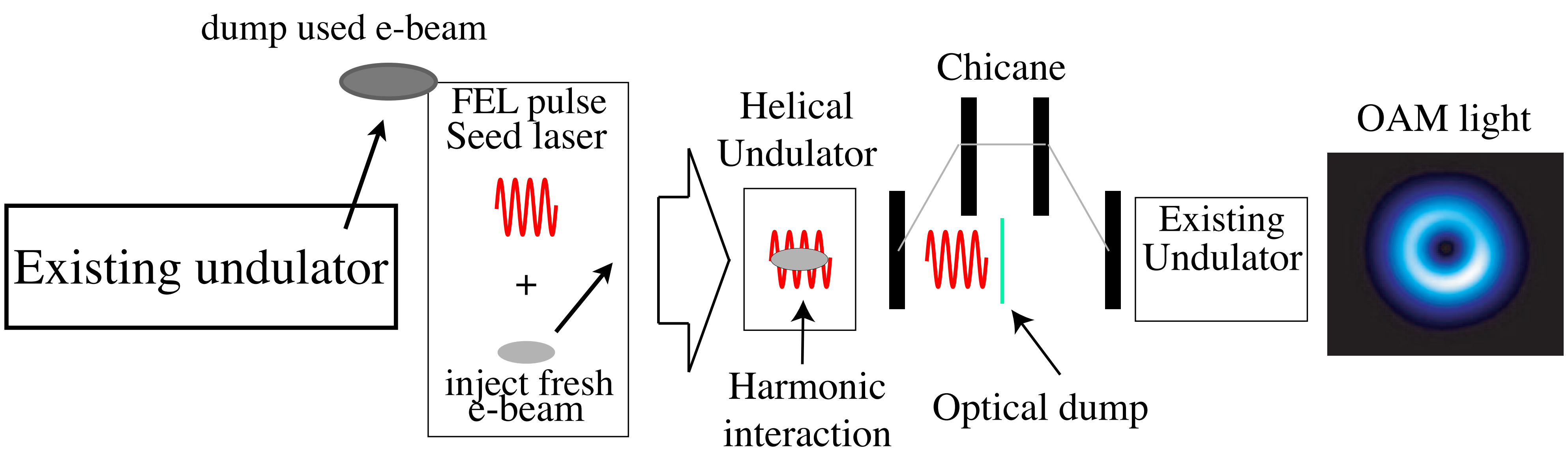
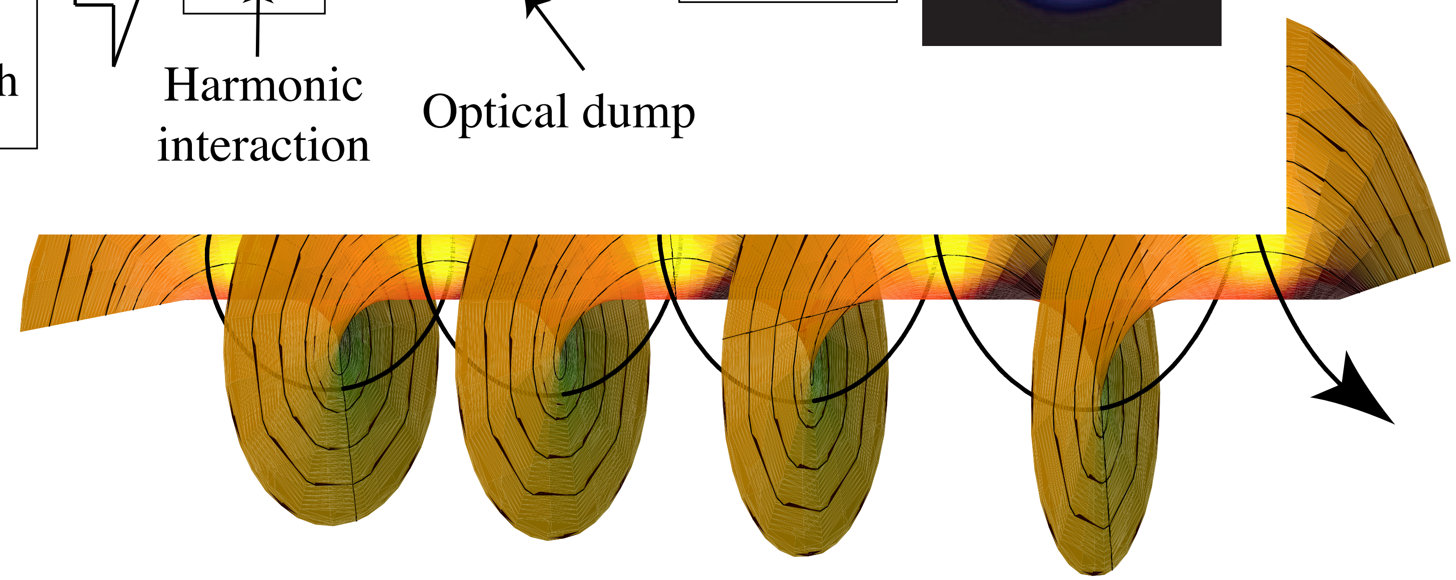
Demonstrate the generation of optical vortices in optical klystron.

H
m
lead
ligl

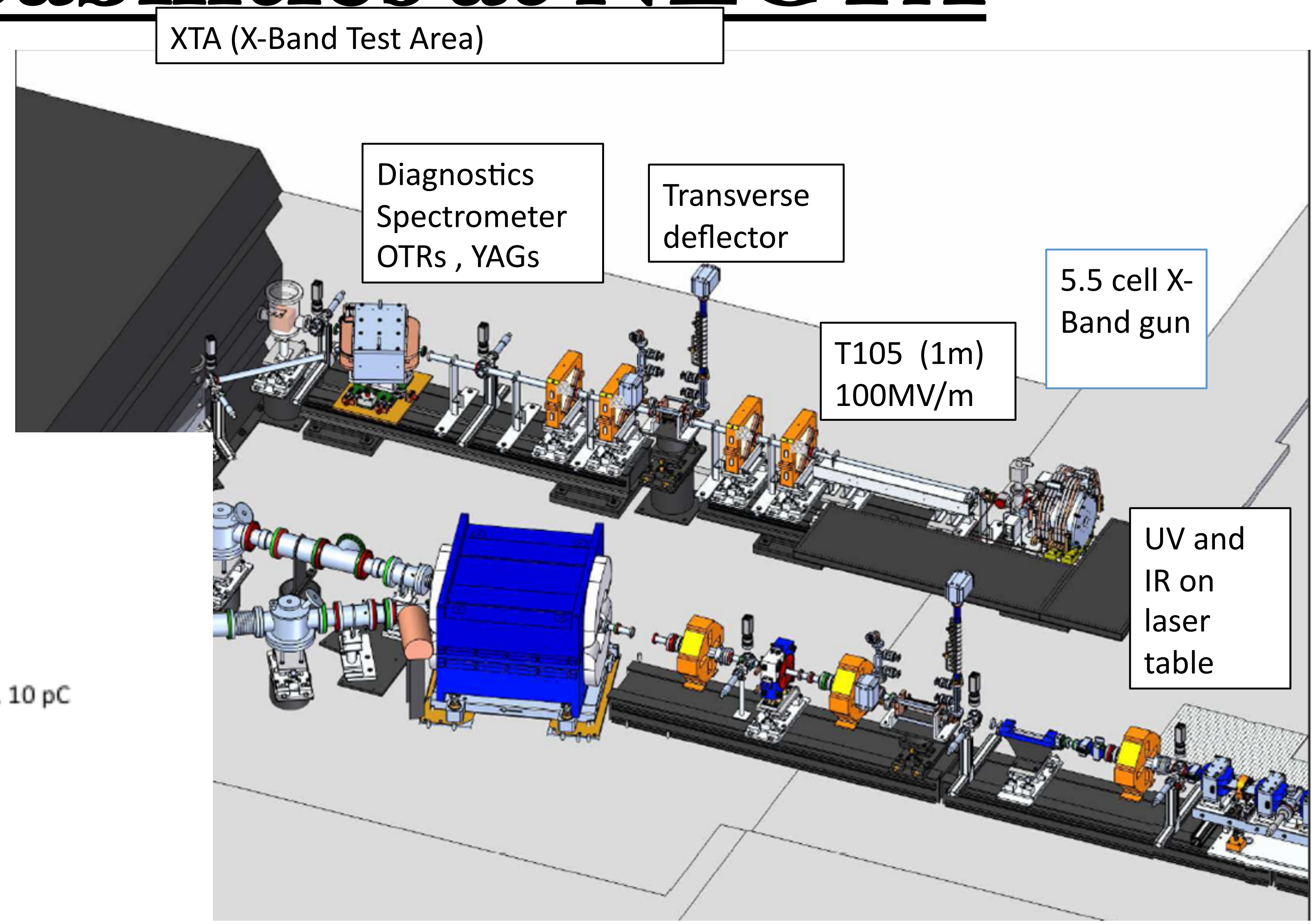


phase fronts →



EH, et al. PRL 106, 164803 (2011)

Other Capabilities at NLCTA



XTA (X-Band Test Area) Program

XTA commissioning starts March 2012
Photo-electron beam expected end of March

- Spring 2012:
  - X-Band gun (Mark-0) brightness measurements:
    emittance, slice emittance, bunch length at 250pc,100pC, 20 pC, 10 pC
  - QE, $\varepsilon_{thermal}$ for V_{rf} up to 200MV/m
  - Low gradient operation

- Summer 2012 :
  - 2-photon emission (IR instead of UV) : QE , $\varepsilon_{thermal}$
  - Laser pulse shaping (blow-out, 2-pulse stacker, transverse)
  - Multibunch with 2 bunches

- Fall 2012 /and 2013
  - low charge 10pC, 5 pC, 1 pC optimization (+compression)
  - Mark-1
  - UCLA X-Band Hybrid gun
  - UED Step 1 (crystal)
  - UED Step 2 (gas phase)
  - Mark-2 (with demountable cathode) (Mg, Mo, CsBr/Cu etc ...)
  - Use best gun for γ Compton Scattering NRF experiment on Rare Earths (see Chris' slides)

Enabled by Echo

Summary

The EEHG beamline and associated architecture (RF systems, laser systems, diagnostics, etc) are versatile, enabling a wide scope of concomitant laser seeding and beam manipulation R&D for FLSs.

Interested in feedback and comments from those interested in advanced beam based seeding schemes, techniques to amplify or (reversibly) suppress instabilities, higher-order optical modes...

Thanks!