XFEL OPERATIONAL FLEXIBILITY DUE TO THE DECHIRPER SYSTEM

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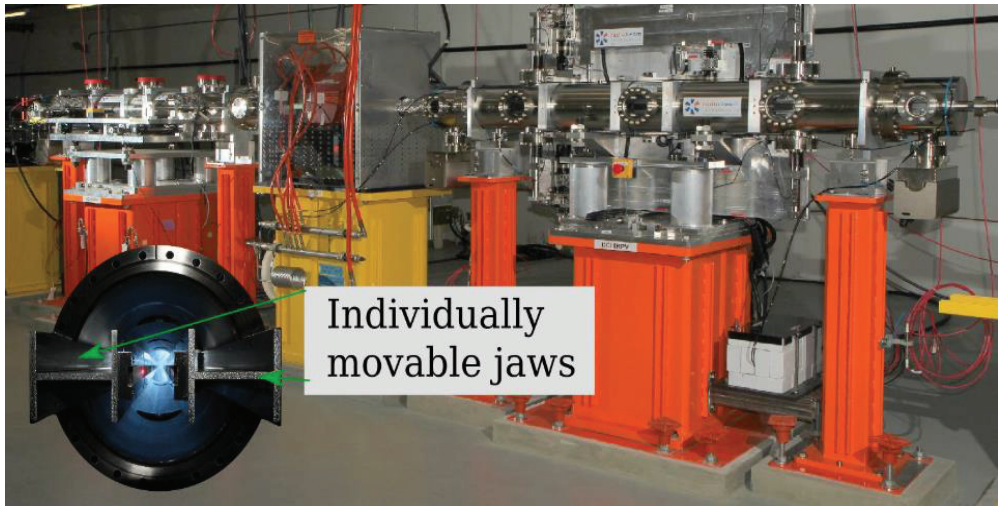
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

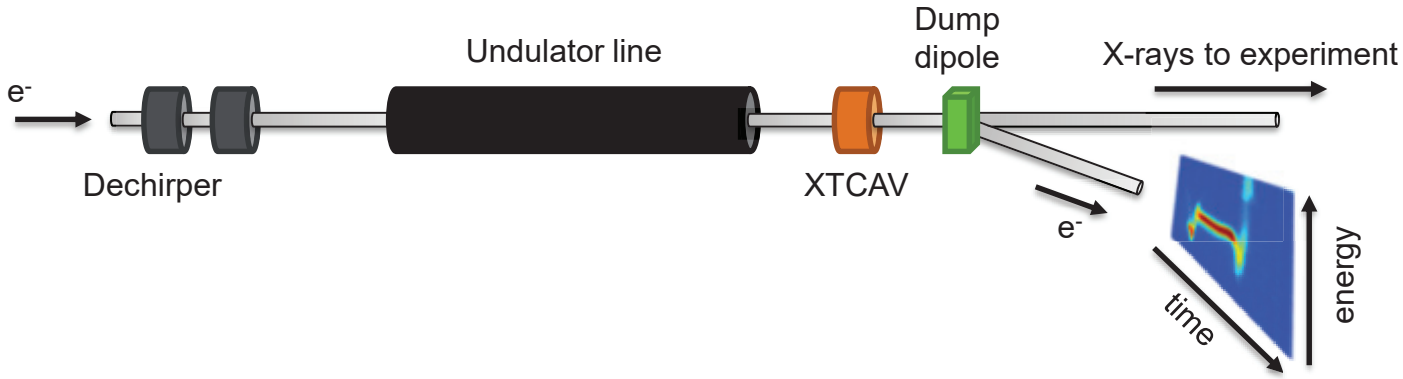
Talk Outline

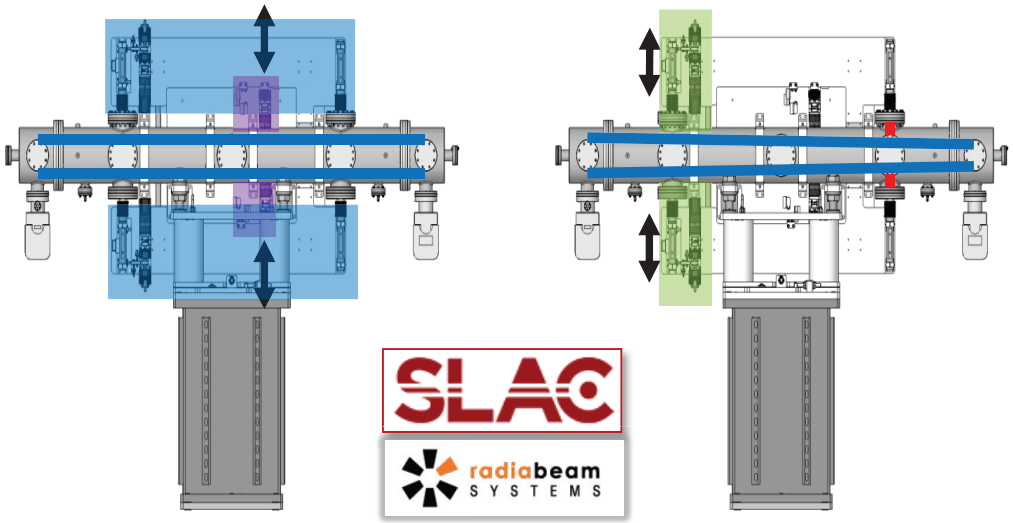
- Dechirper system
  - Device description
  - Interaction with an electron bunch
- Demonstrated applications
  - Energy chirp / FEL bandwidth manipulation
  - Fresh-slice technique
    - Pulse duration control
    - Two/Three-color schemes
    - Multi-stage cascaded amplification
    - Self-seeding schemes
  - Passive Streaking

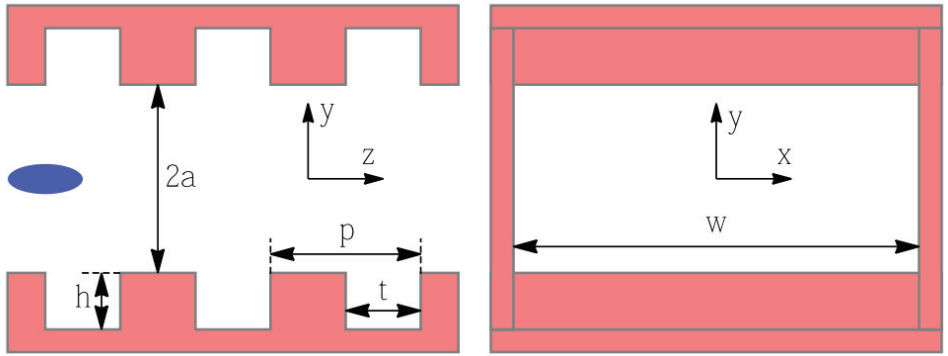
RadiaBeam/SLAC dechirper at the LCLS



- Passive wakefield device
- Corrugated aluminum structure
- 2 modules vertical, horizontal







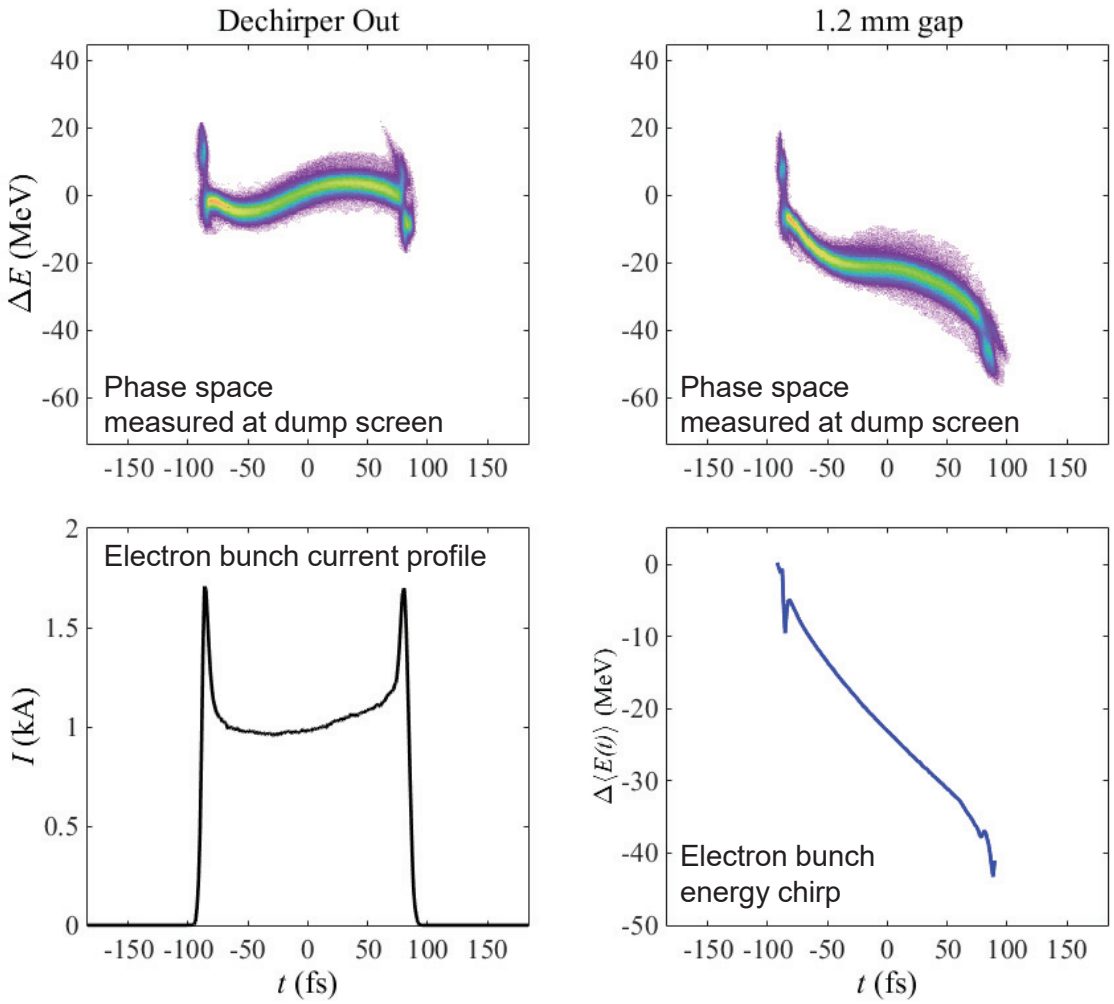
Parameter	Value
Full gap 2a	1 to 20 mm
Period p	0.5 mm
Depth h	0.5 mm
Slit width t	0.25 mm
Fin width w	12 mm
Length L	2 m each

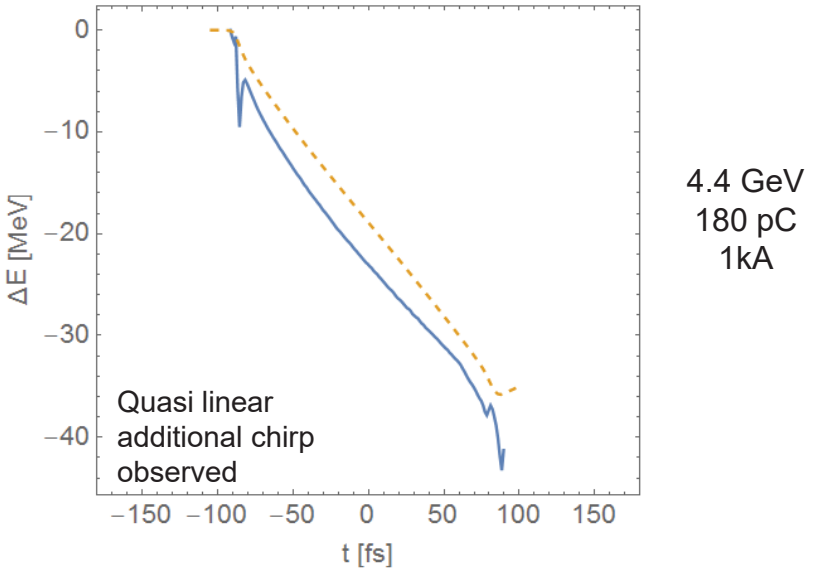
Bane, K. & Stupakov, G. *NIM A* **690**, 106–110 (2012).

Zhang, Z. *et al. Phys. Rev. ST Accel. Beams* 18, 010702 (2015).

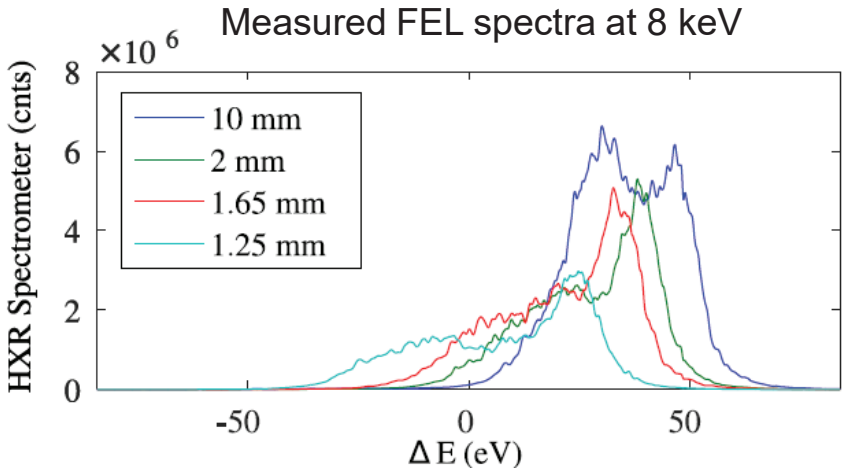
Dechirper wakefields (longitudinal)

- Time-correlated energy losses, controlled by closing gap





4.4 GeV
180 pC
1kA

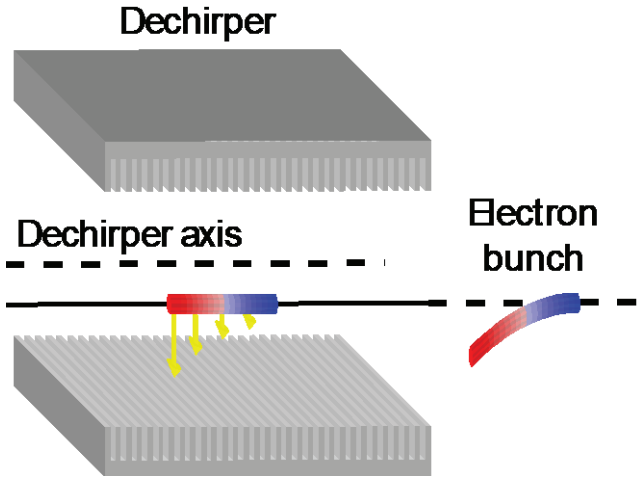


Bane, K., Stupakov, G. et Zagorodnov, I Phys. Rev. ST Accel. Beams **19**, 084401 (2016).

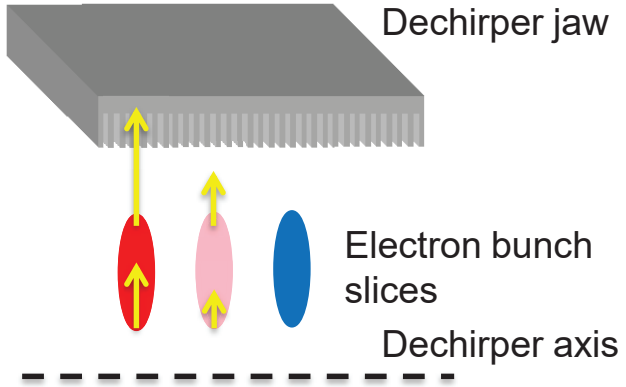
Guetg, M. W. et al. IPAC 2016, pp 809–812

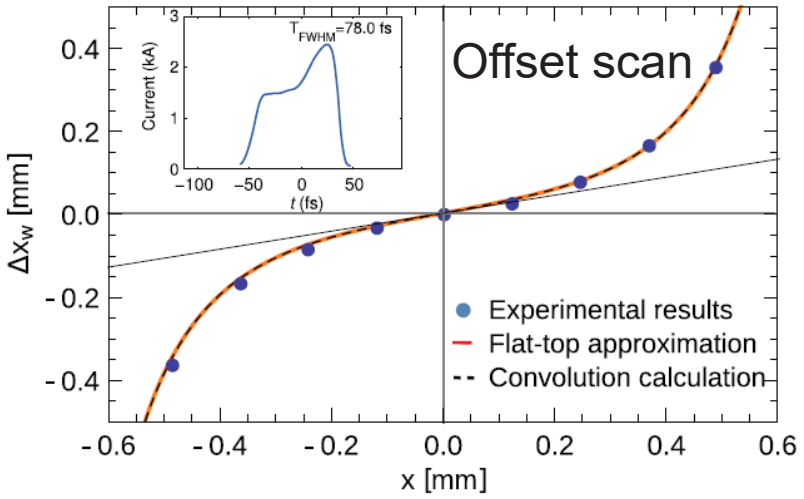
Dechirper wakefields (transverse)

- Time-correlated kick toward metal jaw

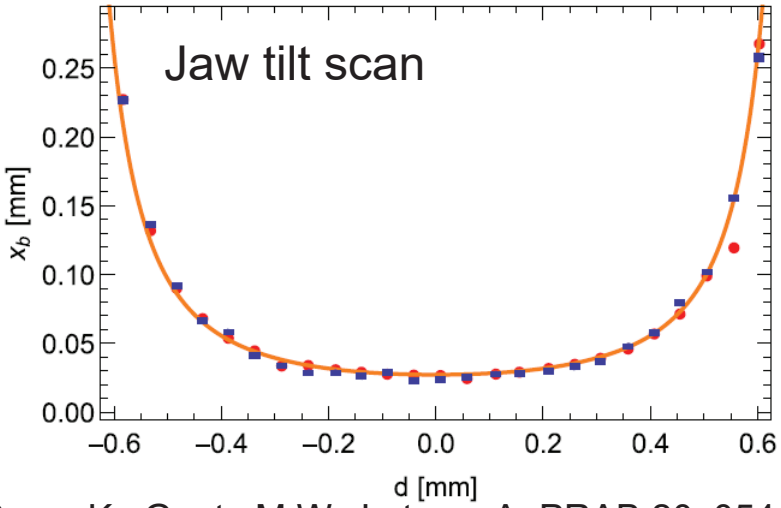


- Time-correlated defocusing





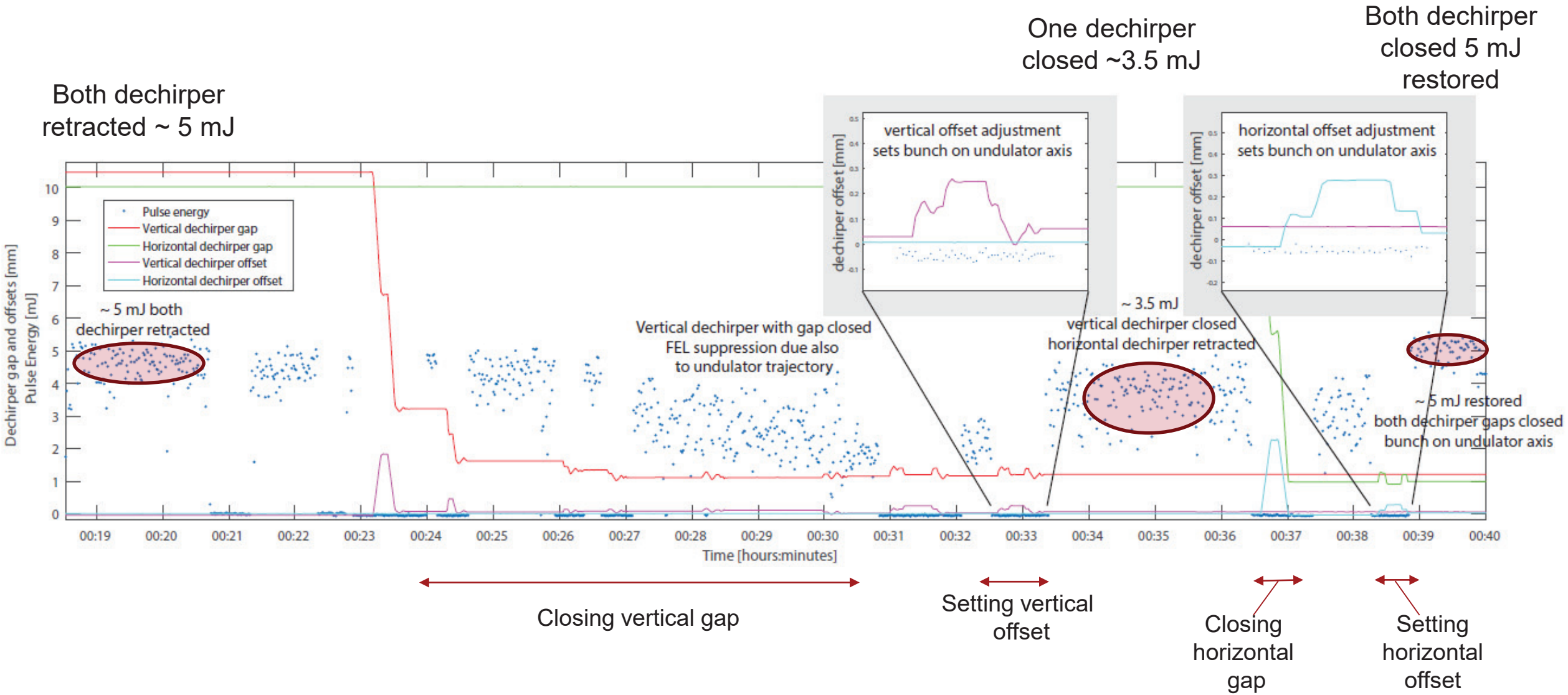
Zemella J. et al. PRAB 20, 104403 (2017)



Bane. K., Guetg M.W., Lutman A. PRAB 20, 054402 (2018)

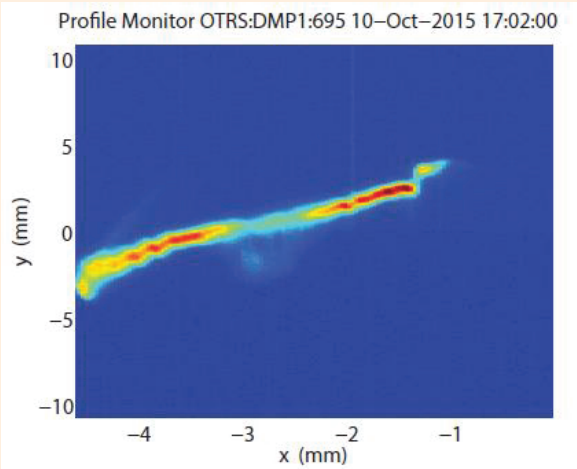
Center of mass kick is used for alignment procedures.

Defocusing compensation for FEL performance



Fresh-slice Free-Electron Lasers (with dechirper)

First observation of Fresh-slice lasing

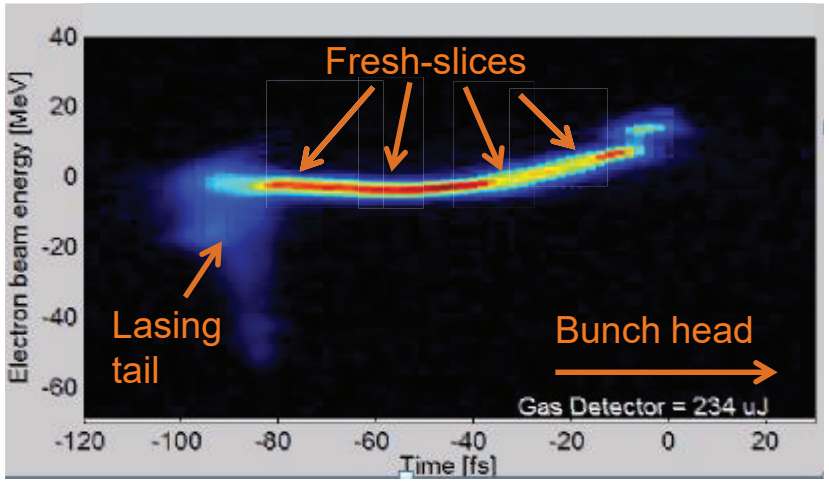


- Fresh-slice allows controlling which electron bunch slice lases in each undulator section, without spoiling the lasing-suppressed electron bunch slices.

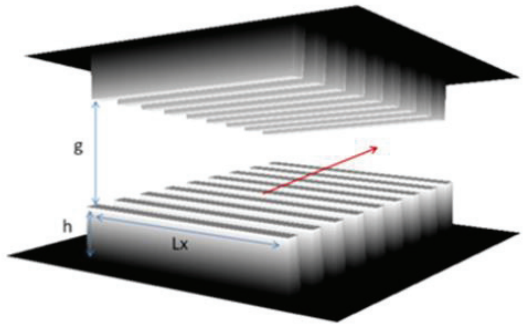
- Why do we call it Fresh-slice?

Be more precise with bunch/slice definition.

Avoid confusion with distinct bunches from the cathode.



- Fresh-slice lasing requires a time-dependent electron slice parameter that can be used to enable or disable the lasing process.



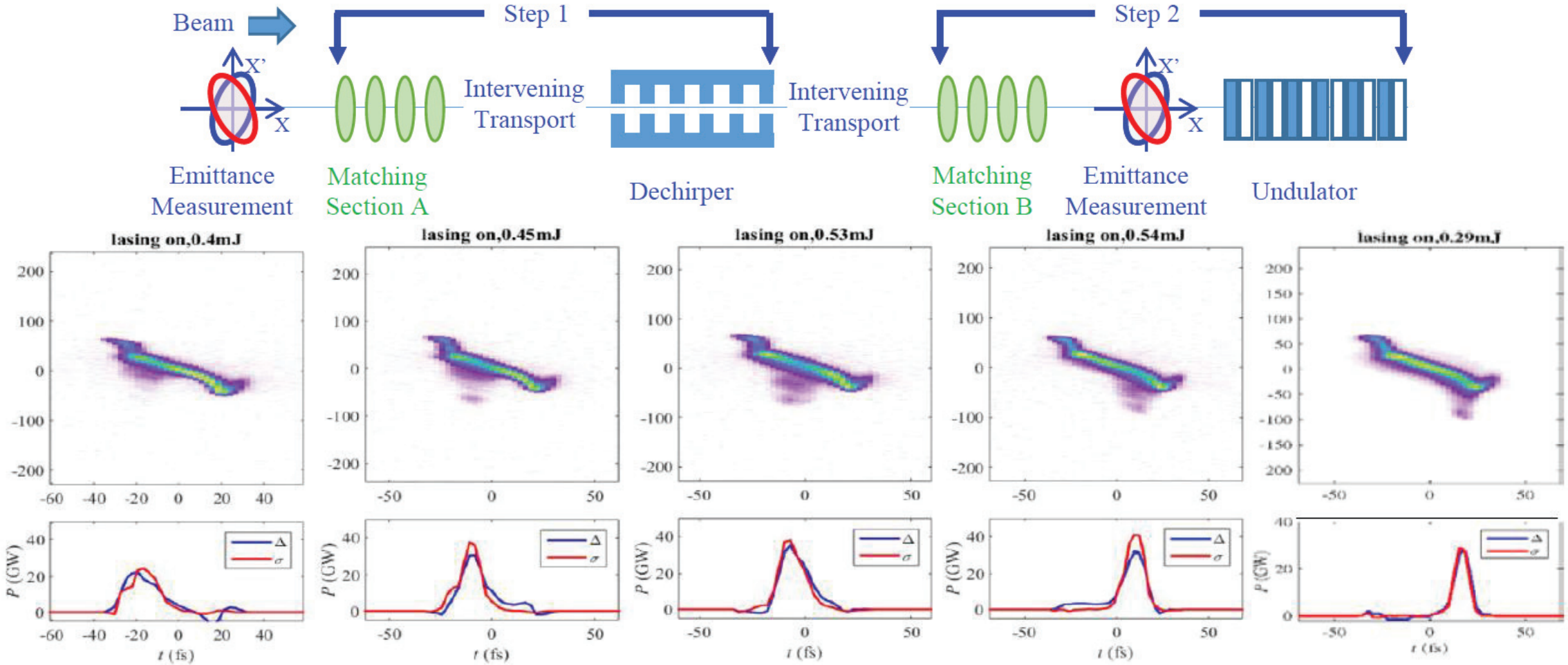
- Time-dependent orbit.
- Time-dependent focusing.

nature photonics
ARTICLES
PUBLISHED ONLINE: 24 OCTOBER 2016 | DOI: 10.1038/NPHOTON.2016.201

Fresh-slice multicolour X-ray free-electron lasers

Alberto A. Lutman[1]*, Timothy J. Maxwell[1], James P. MacArthur[1], Marc W. Guetg[1], Nora Berrah[2], Ryan N. Coffee[1,3], Yuantao Ding[1], Zhirong Huang[1,3], Agostino Marinelli[1], Stefan Moeller[1] and Johann C. U. Zemella[1,4]

Matching-based dechirper Fresh-slice control



PHYSICAL REVIEW ACCELERATORS AND BEAMS **20,** 090701 (2017)

Matching-based fresh-slice method for generating two-color x-ray free-electron lasers

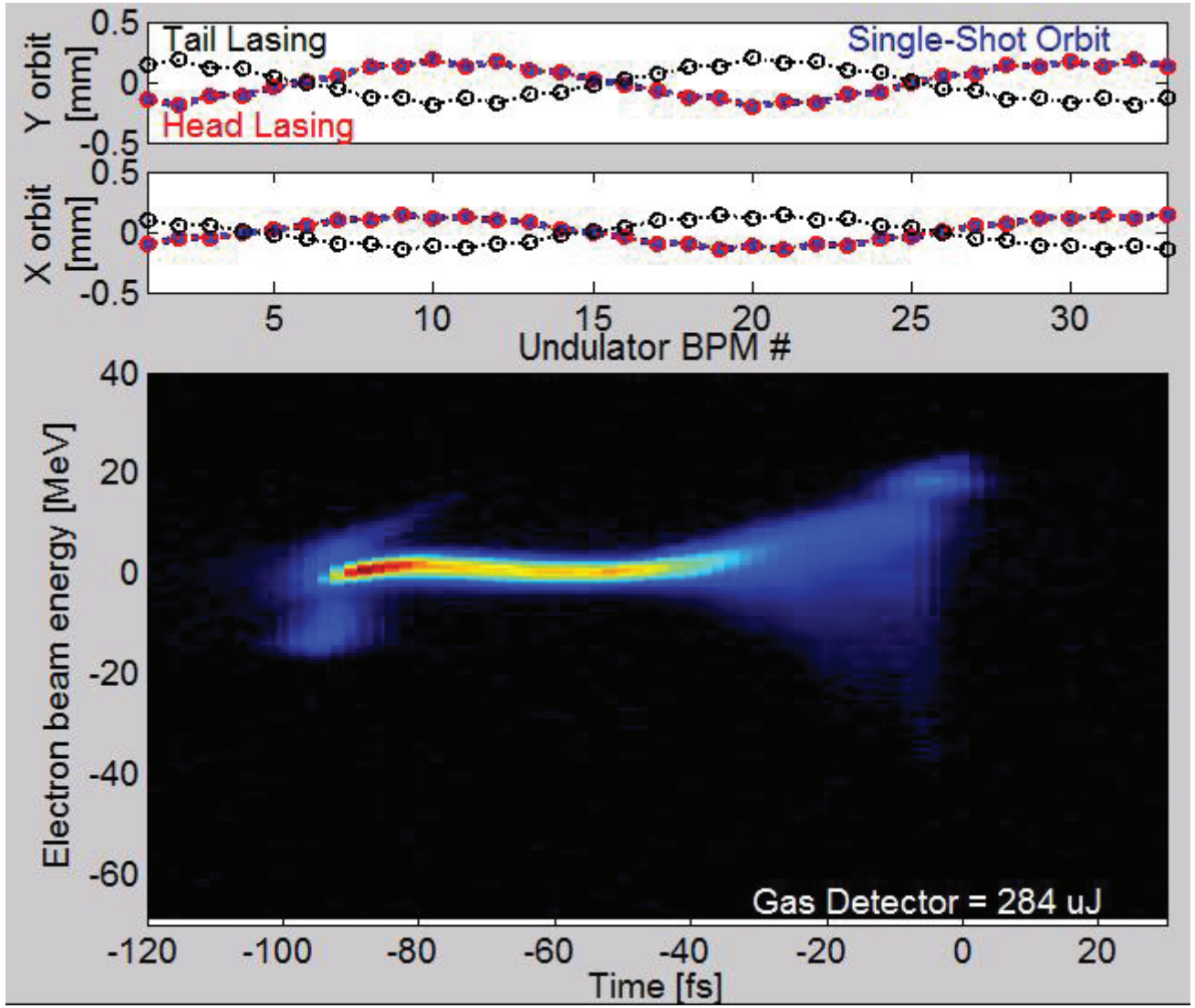
Weilun Qin,[1,2] Yuantao Ding,[2] Alberto A. Lutman,[2] and Yu-Chiu Chao[2,*]

PHYSICAL REVIEW LETTERS **121,** 064802 (2018)

Control of the Lasing Slice by Transverse Mismatch in an X-Ray Free-Electron Laser

Yu-Chiu Chao,[1,*] Weilun Qin,[1,2] Yuantao Ding,[1] Alberto A. Lutman,[1] and Timothy Maxwell[1]
[1]*SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA*
[2]*Institute of Heavy Ion Physics, School of Physics, Peking University, Beijing 100871, China*

Orbit-based dechirper Fresh-slice control

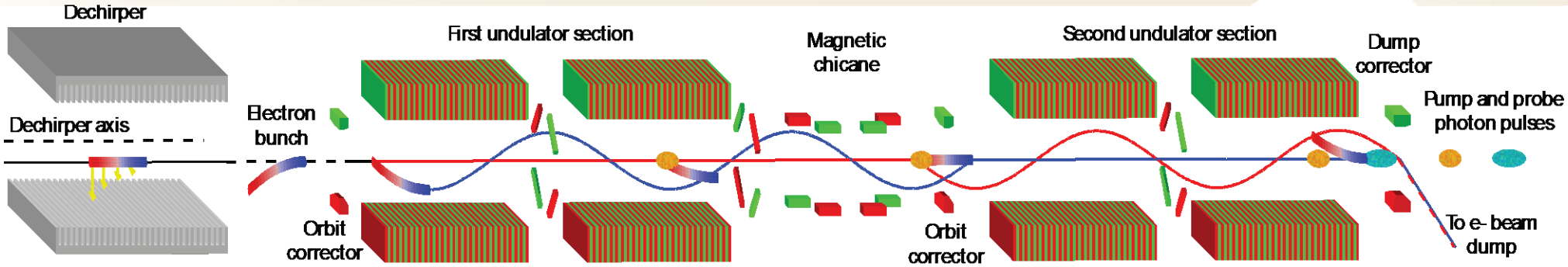


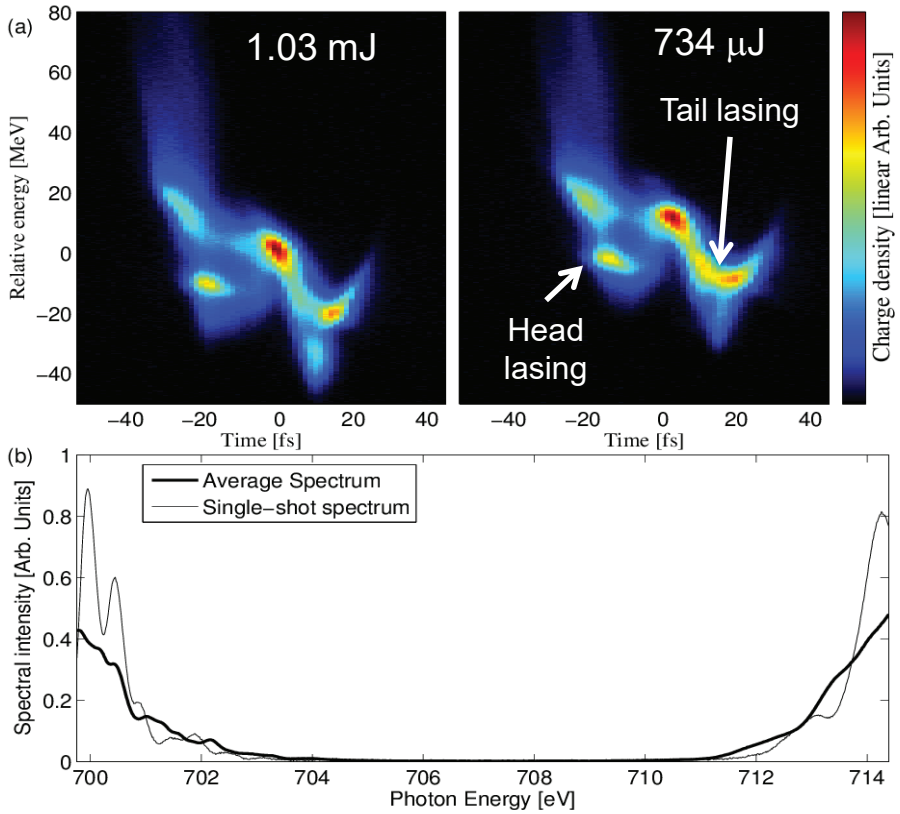
Red orbit: head lasing
Black orbit: tail lasing
Blue orbit: bunch orbit

- 1.8 keV operation
- Bunch head (right)

- Both dechirper used for increased suppression and quadrupole compensation

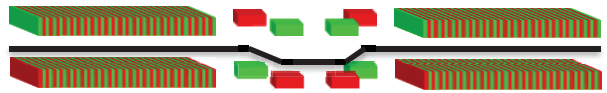
Multi-color Fresh-slice X-ray pulses





- Fully saturated x-ray pulse intensities
- Arbitrary color separation (with variable gap undulators)
- Large delay control up to 1 picosecond
- Independent pointing and polarization control
- Scan smoothly through 0 delay

No chicane delay, pulse on head arrives first



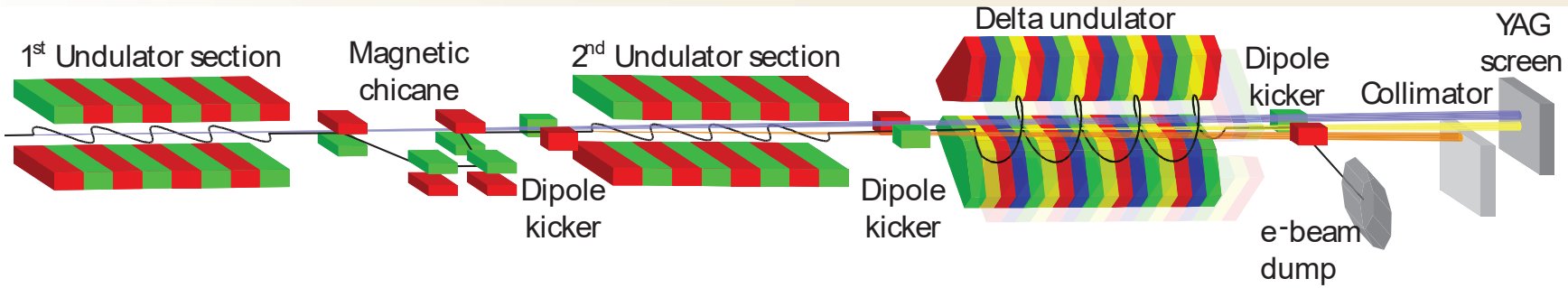
Chicane delays head pulse, scanning delay from small advance to large (1 ps) delays

head pulse ~ 15 fs before tail pulse

Chicane delay >15 fs

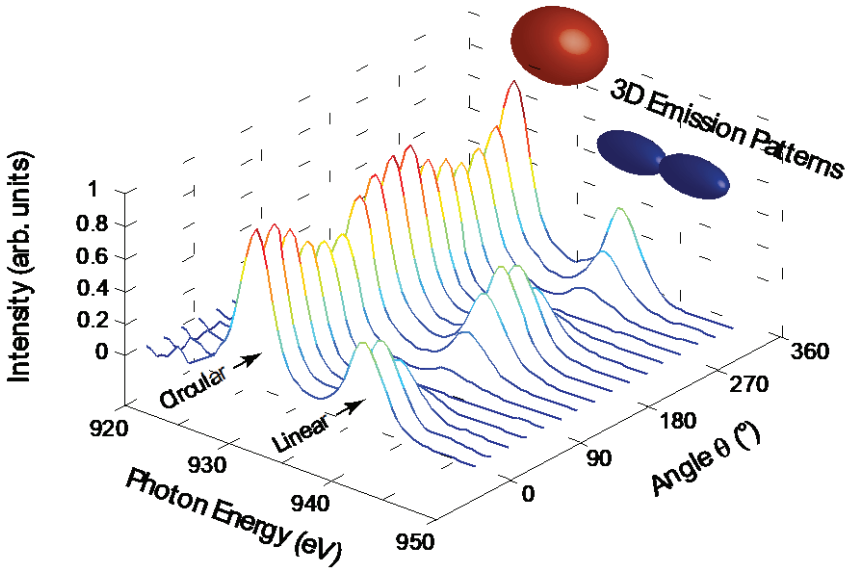
Tail pulse before Head pulse
Max delay ~ 1 ps

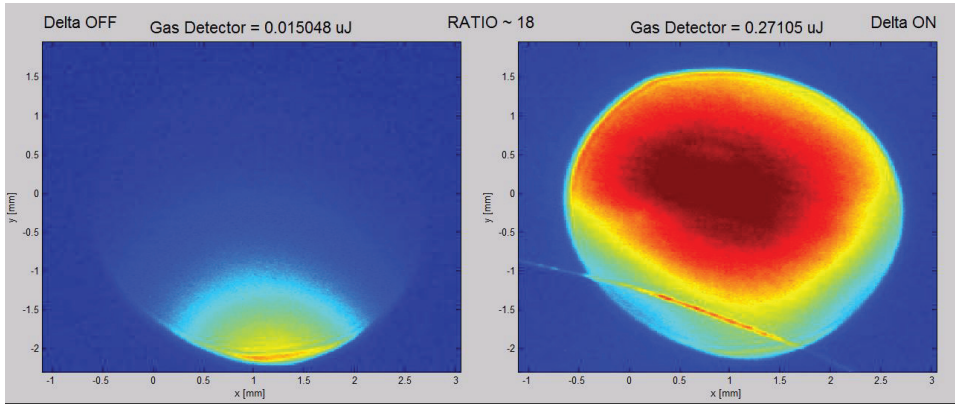
Polarization control and independent pointing

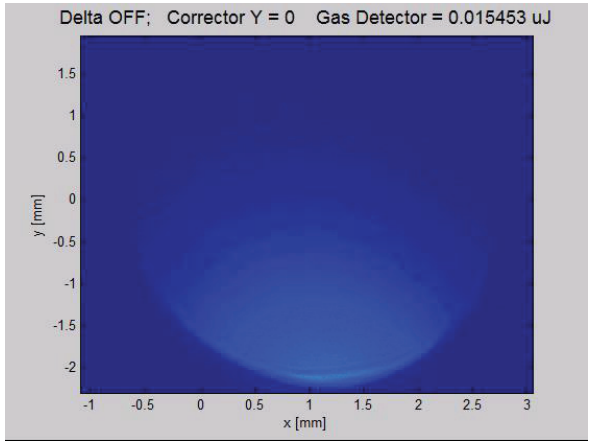


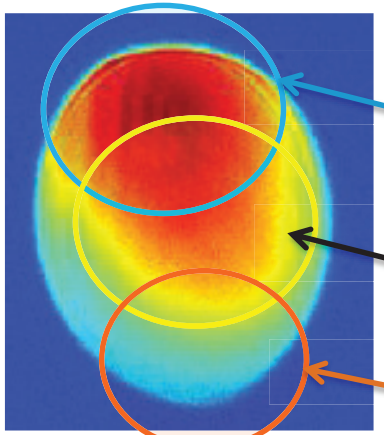
Each undulator section can be full customized

Time-energy Cookiebox measurement









Pump pulse linear polarization

Circularly polarized probe

Linearly polarized beam for bunching to be collimated

Upstream section: 940 eV, linearly polarized
Downstream section: 925 eV, circularly polarized

PHYSICAL REVIEW X 8, 041036 (2018)

Microbunch Rotation and Coherent Undulator Radiation from a Kicked Electron Beam

James P. MacArthur,[1,2,*] Alberto A. Lutman,[1] Jacek Krzywinski,[1] and Zhirong Huang[1,2,†]
[1]SLAC National Accelerator Laboratory, Menlo Park, California 94025, USA
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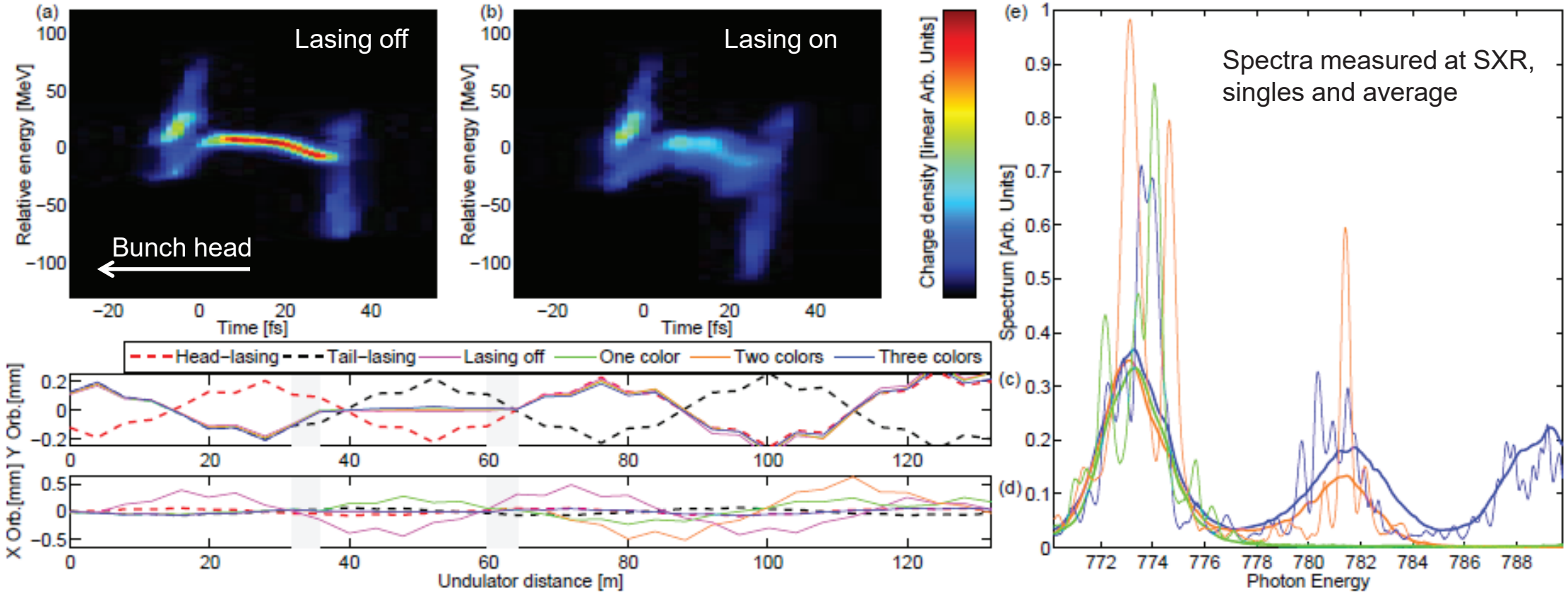
PUBLISHED ONLINE 9 MAY 2016 | DOI: 10.1038/NPHOTON.2016.79
nature photonics

Polarization control in an X-ray free-electron laser

Alberto A. Lutman[1*], James P. MacArthur[1], Markus Ilchen[1,2,3], Anton O. Lindahl[3,4], Jens Buck[2], Ryan N. Coffee[1,3], Georgi L. Dakovski[1], Lars Dammann[5], Yuantao Ding[1], Hermann A. Dürr[1,3,6], Leif Glaser[5], Jan Grünert[2], Gregor Hartmann[5], Nick Hartmann[1,7], Daniel Higley[1], Konstantin Hirsch[1], Yurii I. Levashov[1], Agostino Marinelli[1], Tim Maxwell[1], Ankush Mitra[1], Stefan Moeller[1], Timur Osipov[1], Franz Peters[1], Marc Planas[2], Ivan Shevchuk[5], William F. Schlotter[1], Frank Scholz[5], Jörn Seltmann[5], Jens Viefhaus[5], Peter Walter[5], Zachary R. Wolf[1], Zhirong Huang[1,3] and Heinz-Dieter Nuhn[1]

Fresh-slice: Three color operation

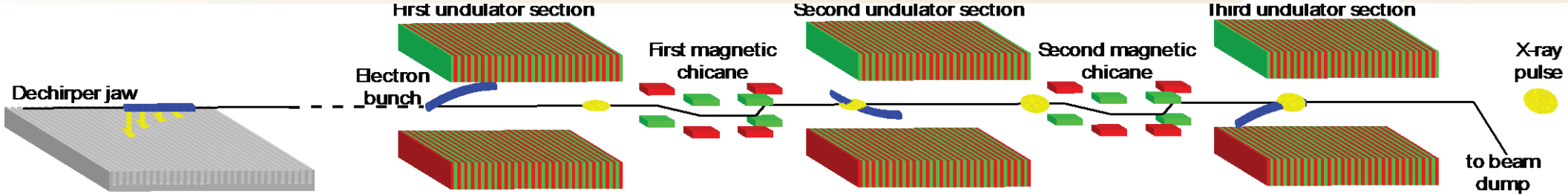


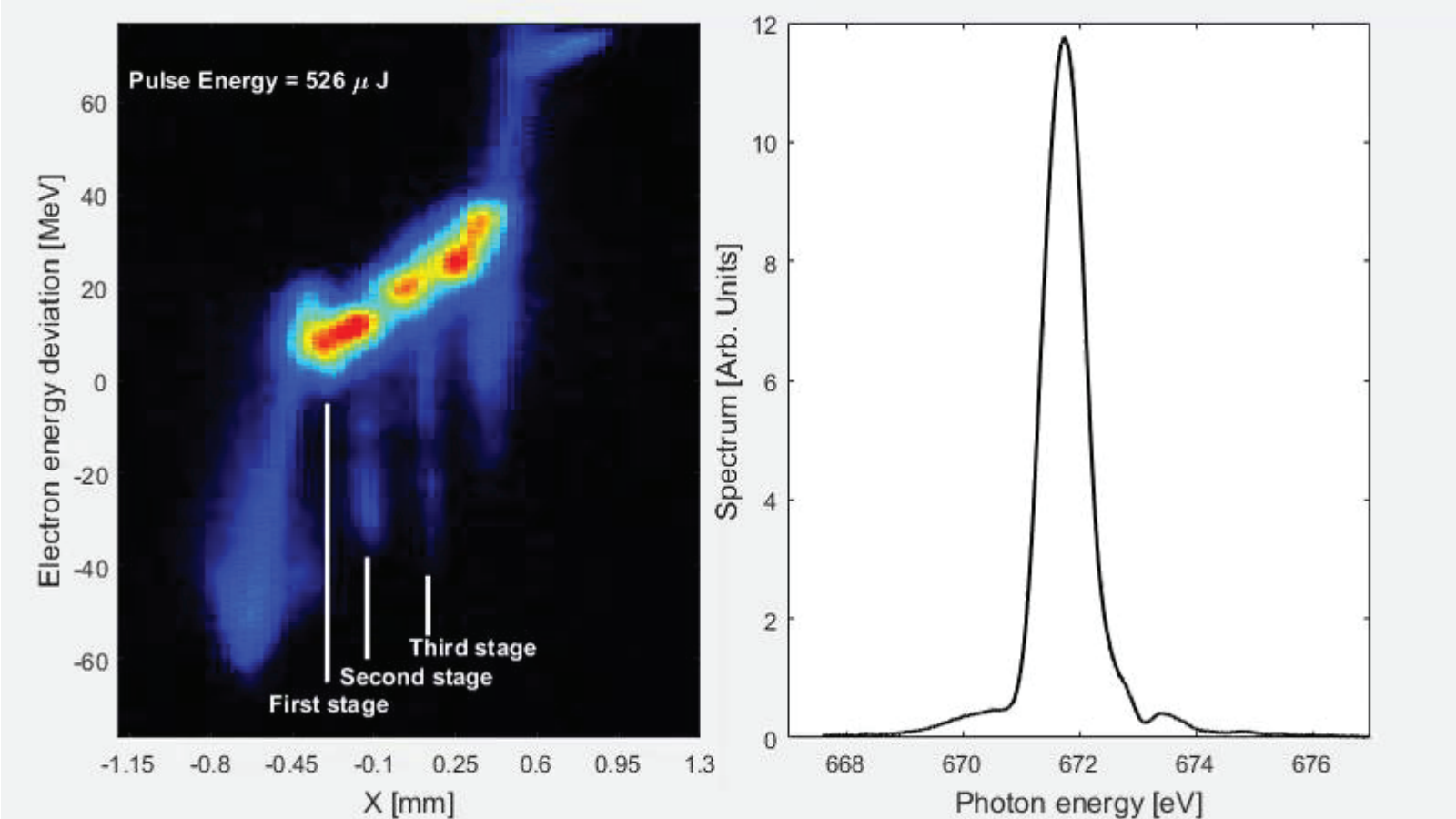
Demonstration performed at 780 eV.

- Tail lasing in first section
- Core lasing in second section
- Head lasing in third section

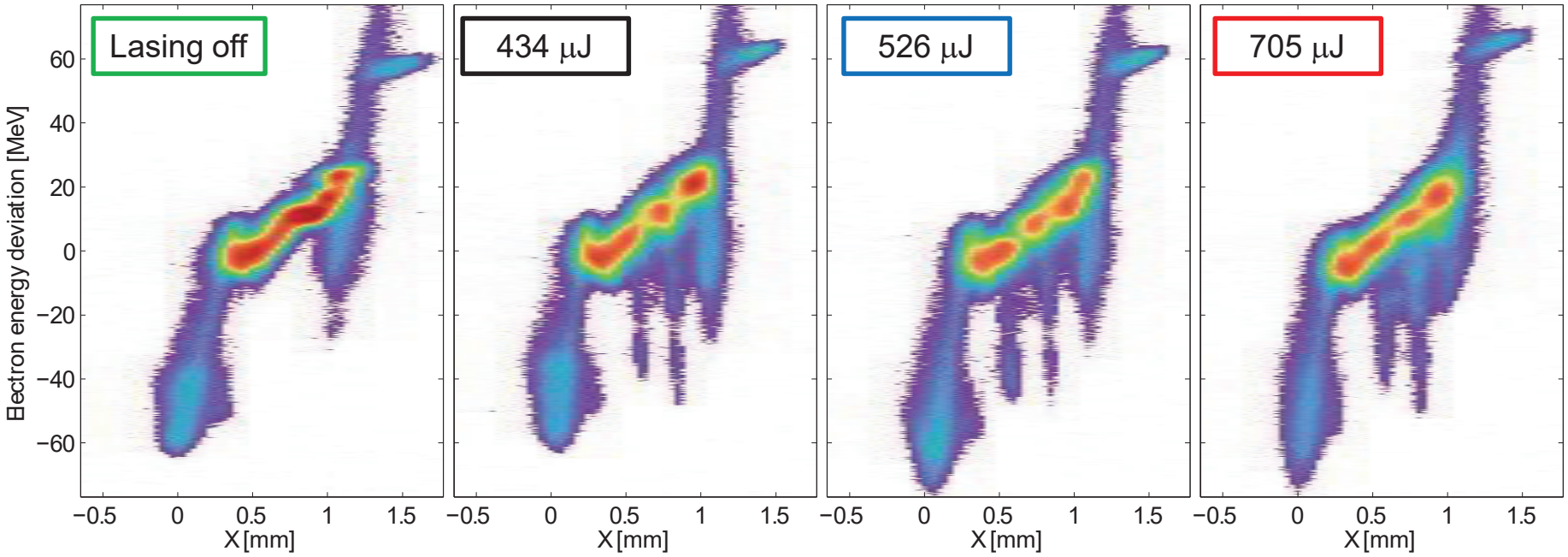
	Tail Pulse	Core Pulse	Head pulse
Energy	88 μJ	75 μJ	71 μJ
Duration	~ 7 fs	~ 10 fs	~ 10 fs
Photon En.	772 eV	780 eV	788 eV
Undulators	U1-U8	U10-U15	U17-U33

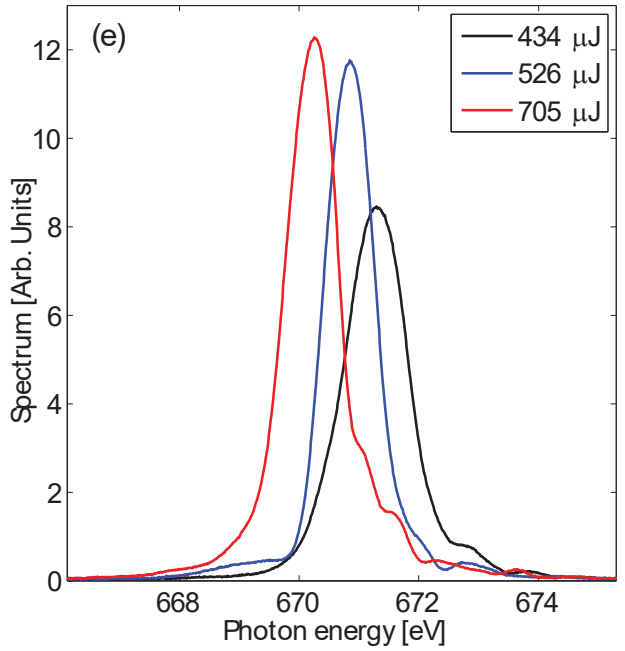
Fresh-slice Multi-stage amplification
High power, femtosecond x-rays

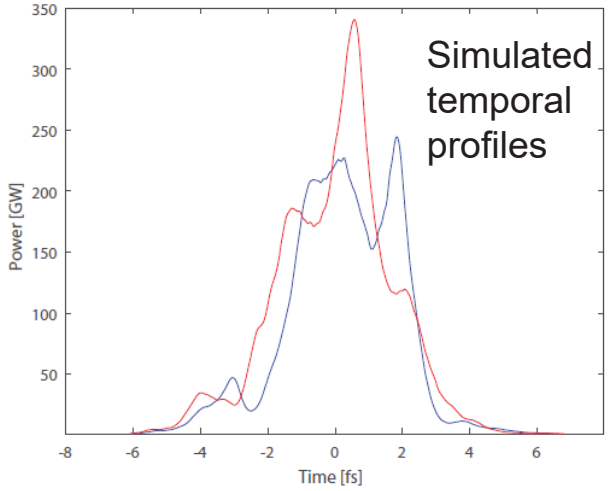




Fresh-slice Multi-stage amplification
High power, femtosecond x-rays







1 Spike	2 Spikes	3 Spikes	>3 Spikes
13%	36%	36 %	15 %
304 μJ	299 μJ	289 μJ	235 μJ

200-300 GW power single spikes at SXR
~10x than regular SASE.

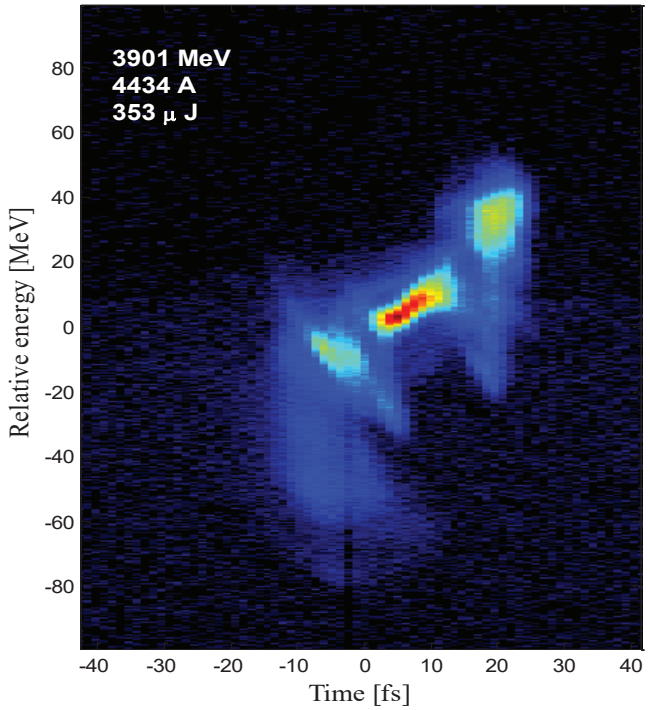
PHYSICAL REVIEW LETTERS **120,** 264801 (2018)

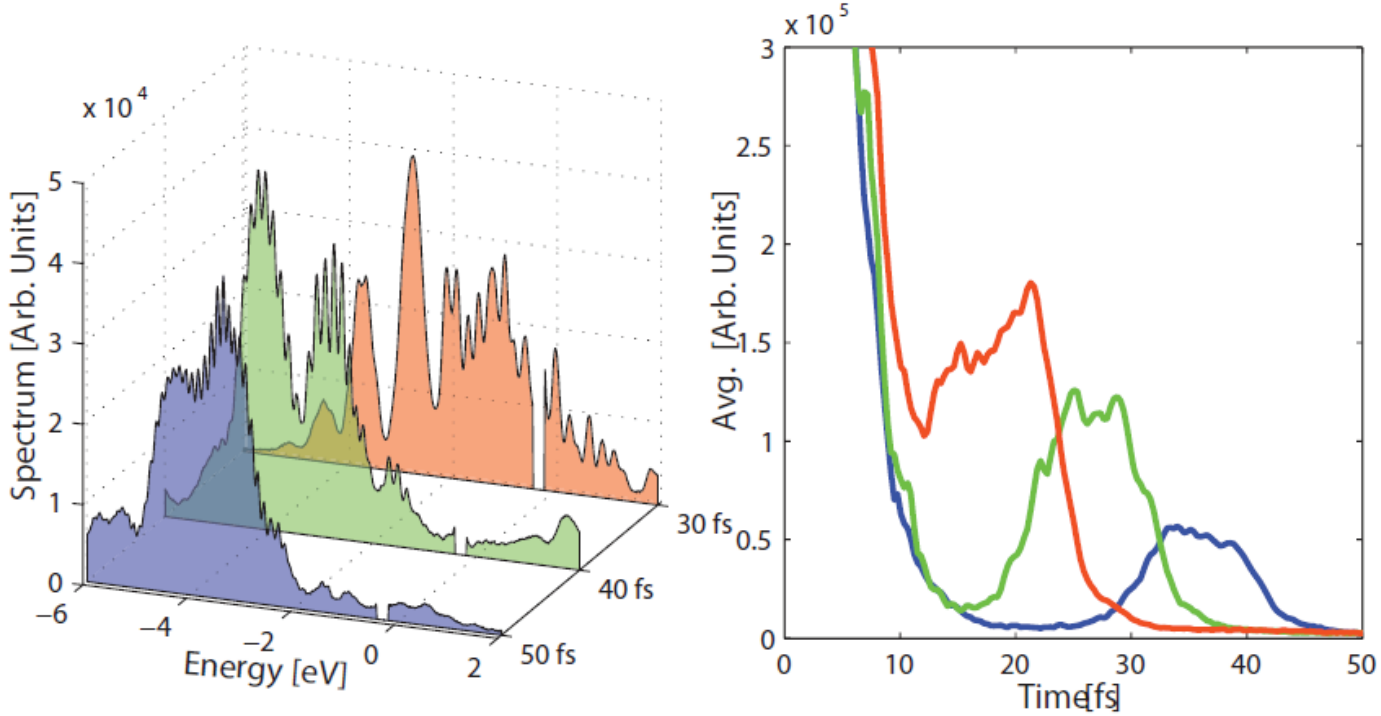
Featured in Physics

High-Power Femtosecond Soft X Rays from Fresh-Slice Multistage Free-Electron Lasers

Alberto A. Lutman,* Marc W. Guetg, Timothy J. Maxwell, James P. MacArthur, Yuantao Ding, Claudio Emma, Jacek Krzywinski, Agostino Marinelli, and Zhirong Huang

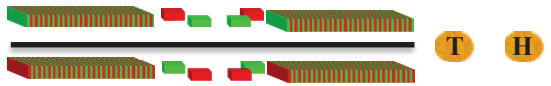
Fresh-slice Two-stage pump / one stage probe



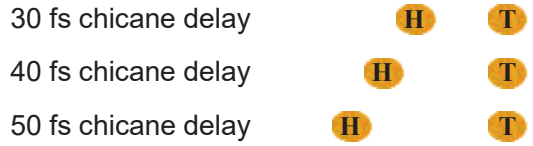


Fringes Fourier analysis allows to determine the actual delay between x-ray pulses

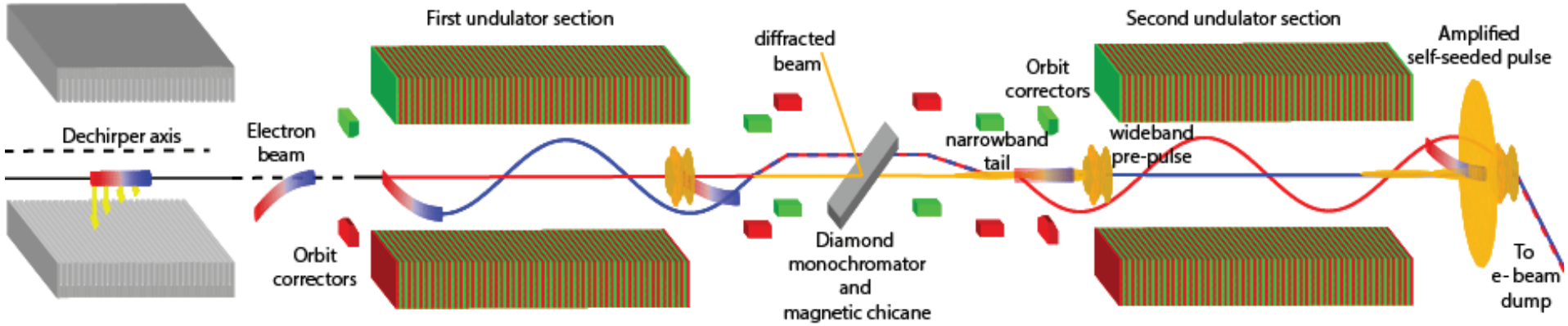
- 160 μJ total (on average)
- 2-stage pump, 1-stage probe
- ~30 fs chicane delay sets tail pulse ~15 fs before head pulse
- Same wavelength set by K.

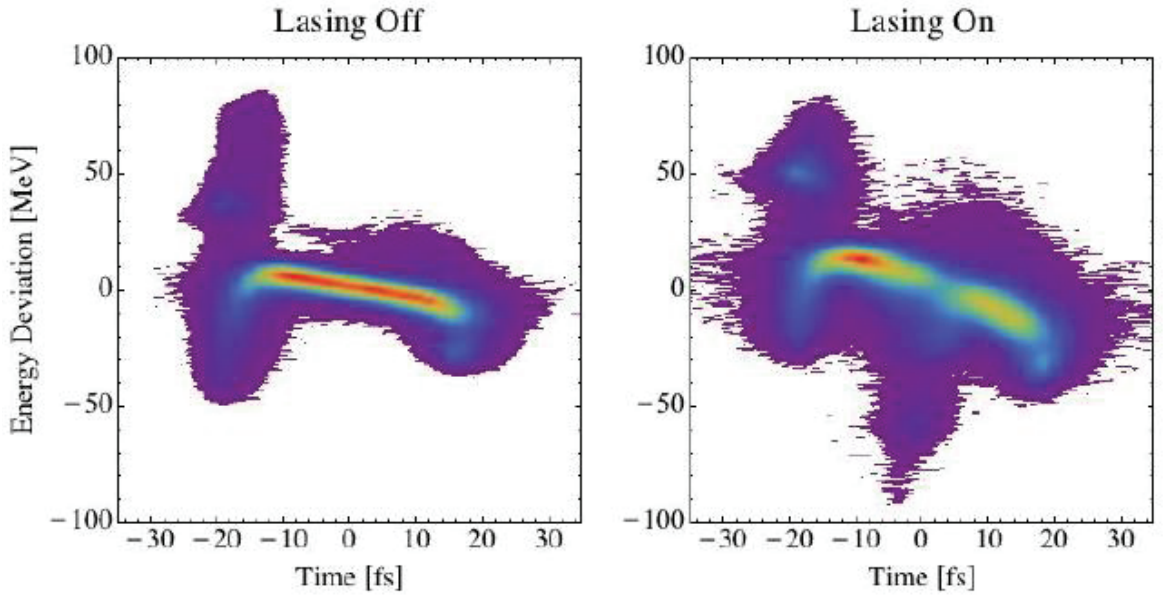


Chicane off~15 fs head advance



Fresh-slice: hard X-ray self-seeding.

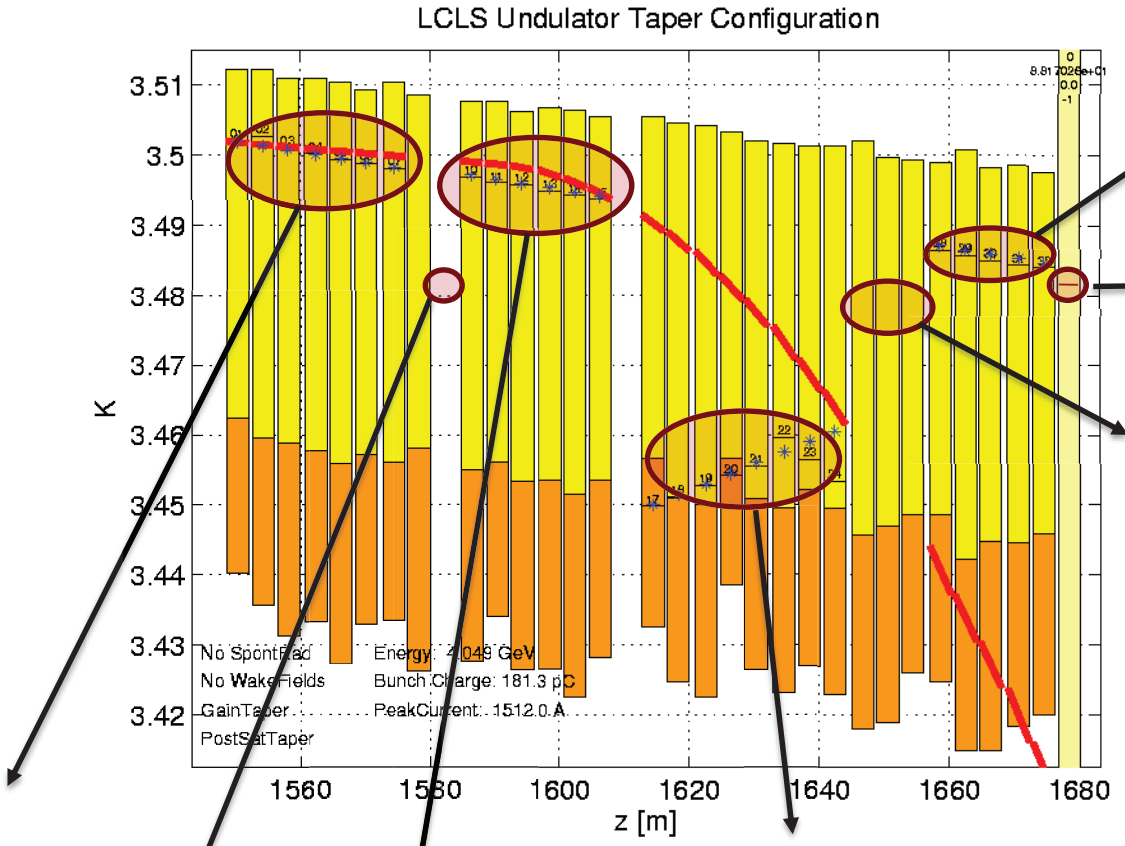




- Eliminates trade off between seed power at the diamond and energy spread increase in the electron bunch
- Higher power than regular self-seeding (~2x demonstrated)
- Amplification of a large seed avoids saturation issues in a long radiator section

C. Emma, A. Lutman, M. Guetg, J. Krzywinski, A. Marinelli, J. Wu and C. Pellegrini, "Experimental demonstration of fresh bunch self-seeding in an X-ray free electron laser", *Appl. Phys. Lett.* **110** 154101

Fresh-slice: Soft X-ray self-seeding
Seeding Variable Polarization Delta Undulator



SASE pulse
Bunch tail

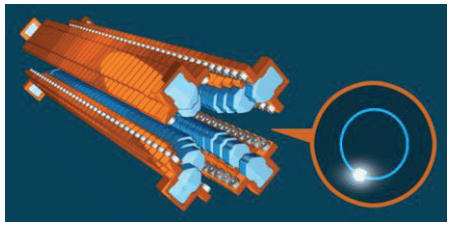
Seeded Pulse
Bunch tail

Bunch kicked.
GW monochromatic
Seed freely propagates

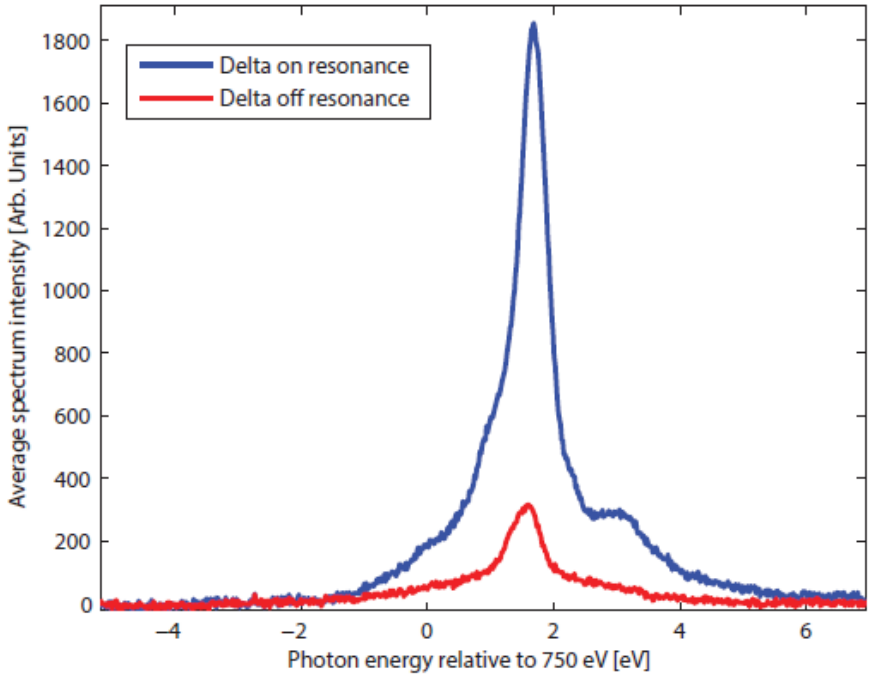
SXRSS grating
monochromator

Seed picked up by undulator
In proximity of Delta.

Undulator out
Orbit set for
head-lasing

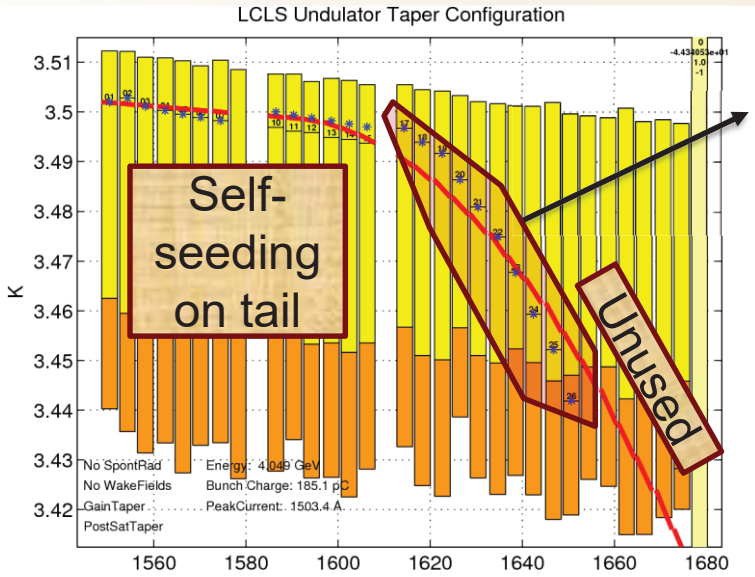


Delta, variable polarization
afterburner.

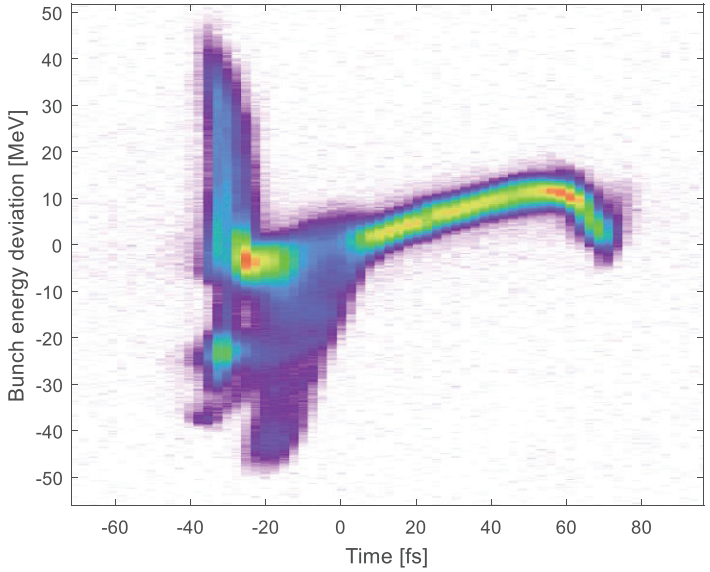


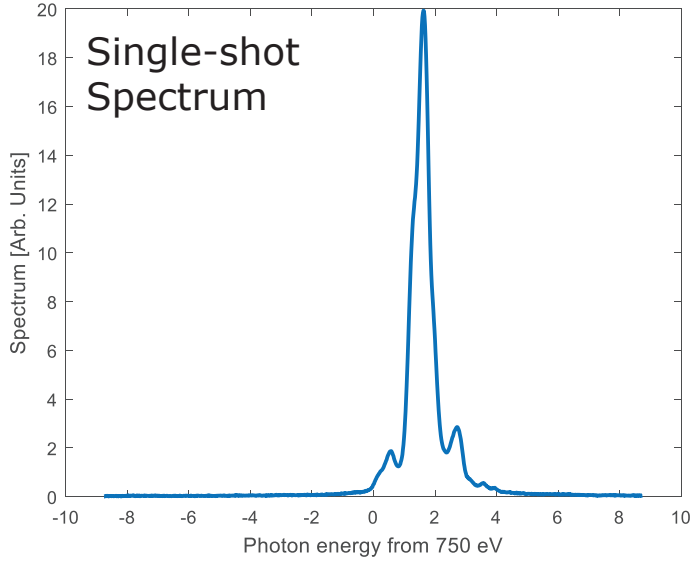
Amplification of narrow-bandwidth
self-seeded line in Delta undulator

Fresh-slice: Soft X-ray self-seeding
Three cascaded stages



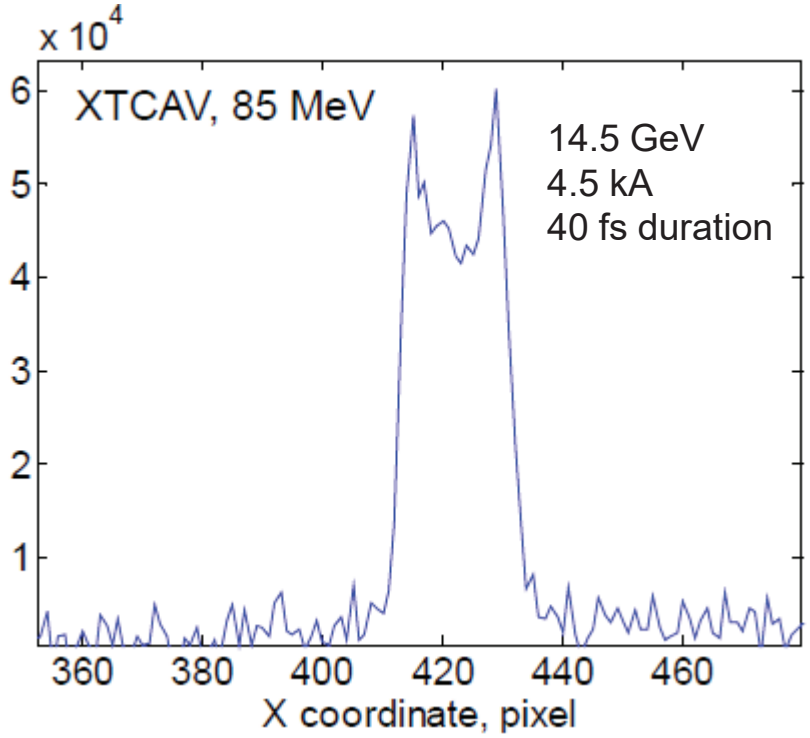
- Third stage picks up high-power seed on bunch head. Strong post-saturation taper.
- Stable wavelength
- Best performance:
  ~10 fs, 350 μJ, 0.6 eV bandwidth.

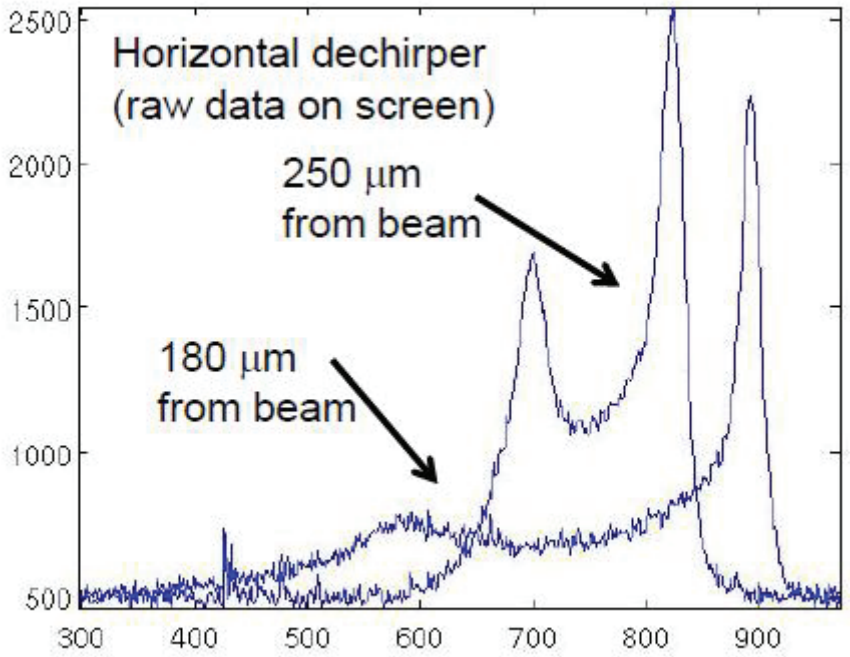




Passive streaking

Passive streaking can reveal more electron bunch time-resolved details than 85 MeV XTCAV





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THANK YOU FOR YOUR ATTENTION