Dechirper experience at the LCLS

8th Hard X-ray FEL Collaboration Meeting
Pohang, 24-26 October 2016

A. Lutman

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Talk Outline

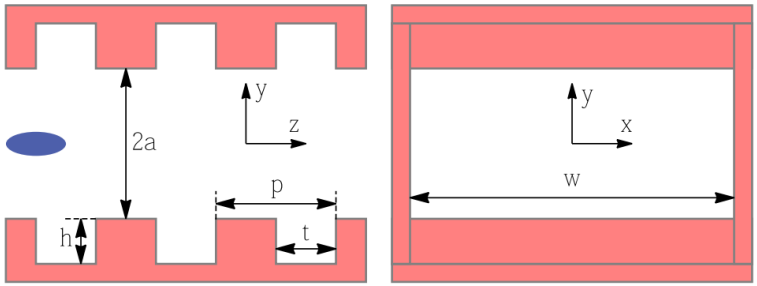
- Dechirper system
  - What is a dechirper
  - Interaction with an electron bunch

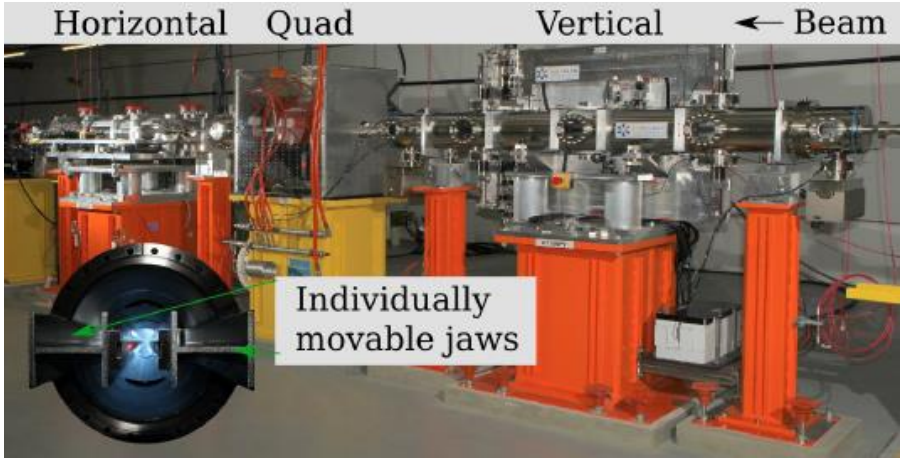
- Demonstrated applications
  - Time-energy phase space manipulation
  - Passive streakers
  - Fresh-slice free electron lasers
    - Pulse duration control
    - Two-colours FEL
    - Polarization control of probe
    - Three colours FEL
    - Enhanced HXR self-seeding

- Final remarks

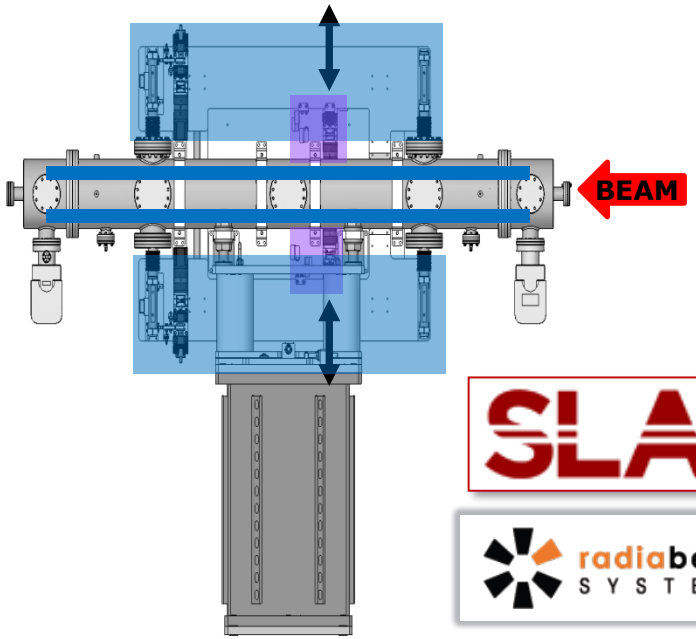
Dechirper system

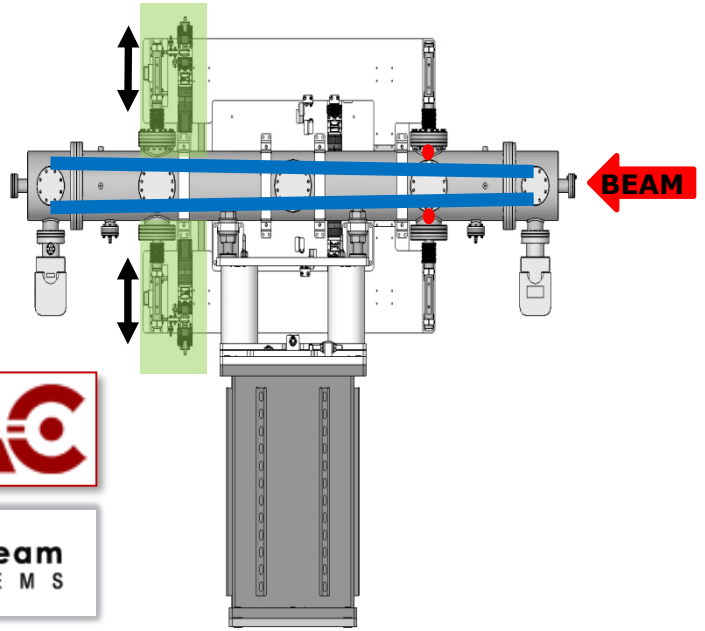
- Passive wakefield device
- Corrugated structure in aluminum
- Two modules, one horizontal, one vertical





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





SLAC

radiabeam SYSTEMS

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

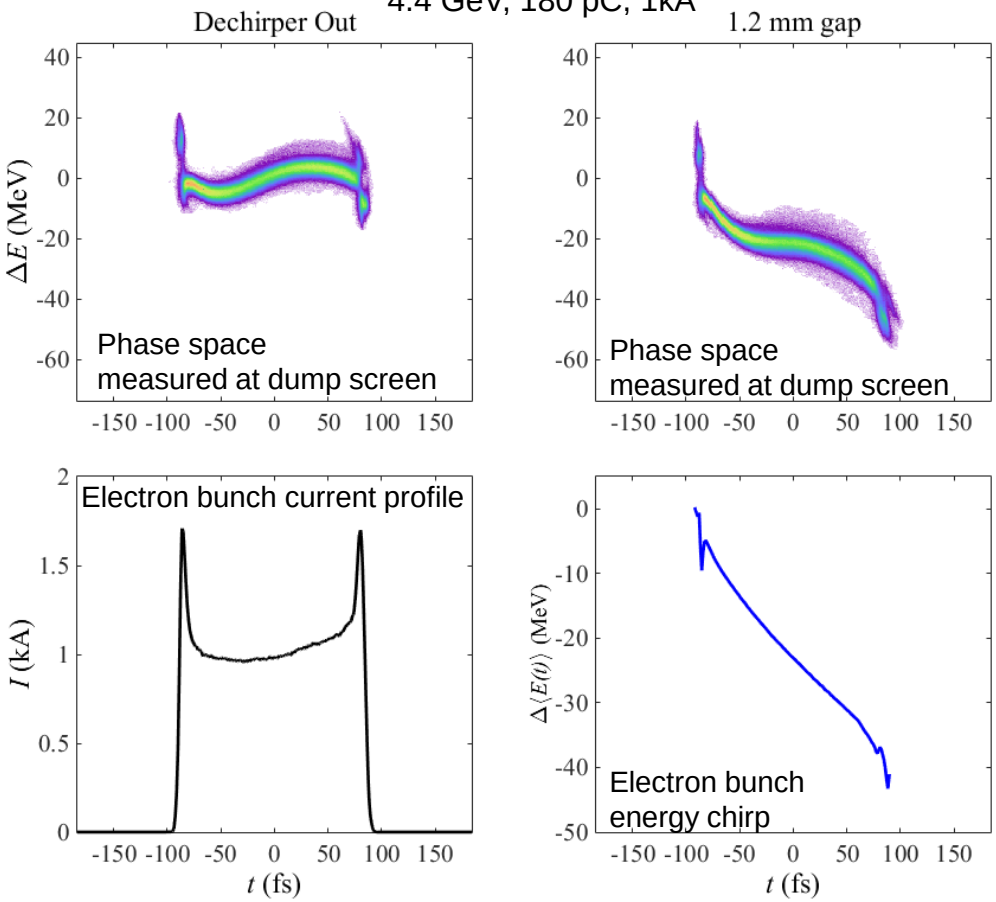
Zhang, Z. *et al. Phys. Rev. ST Accel. Beams* 18, 010702 (2015).

Effects of wakefield on the electron bunch: Longitudinal wakes

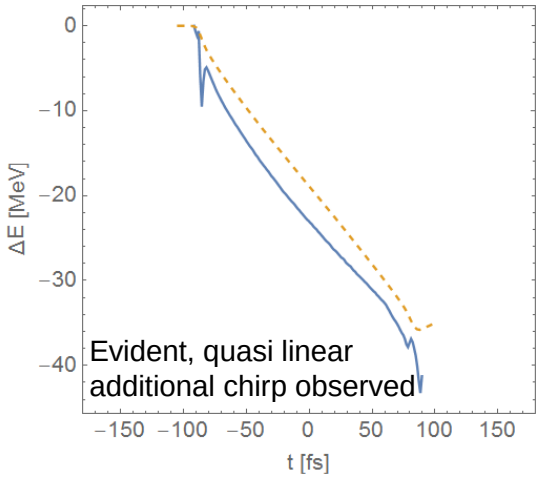
➢ Travelling on axis. Narrower gap increases the energy losses

Emma, P. , Venturini, M., Bane, K. ,Stupakov, G., Kang, H.-S., Chae, M. S., Hong, J., Min, C.-K. ,Yang,H. Ha, T. , Lee, W. W. , Park, C. D. , Park, S. J. , Ko, I. S., Experimental Demonstration of Energy-Chirp Control in Relativistic Electron Bunches Using a Corrugated Pipe, *Phys. Rev. Lett.* **112** 034801

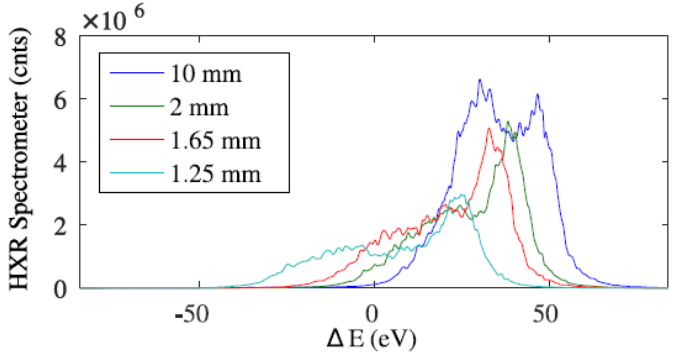
4.4 GeV, 180 pC, 1kA



4.4 GeV, 180 pC, 1kA



Bandwidth control at 8 keV

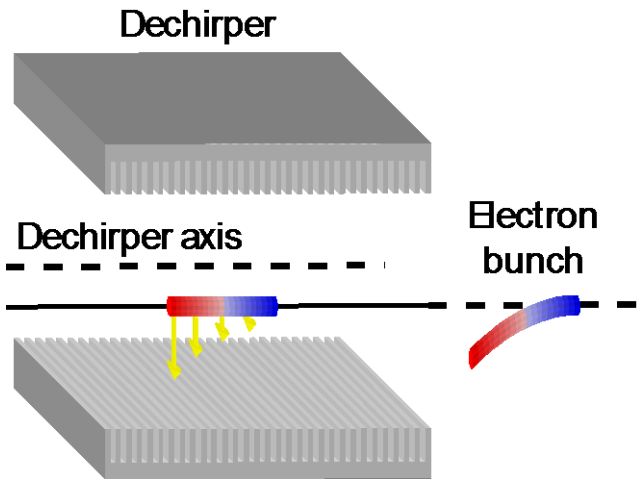


Guetg, M. W. et al. IPAC 2016, pp 809–812

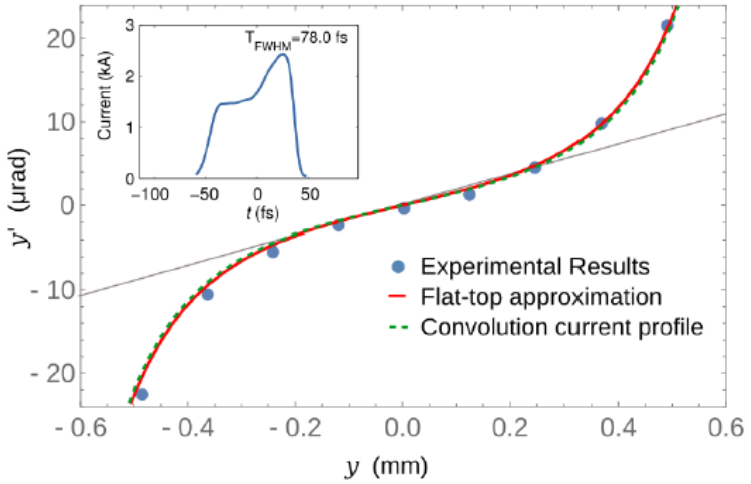
Bane, K., Stupakov, G. & Zagorodnov, I *Phys. Rev. ST Accel. Beams* **19**, 084401 (2016).

Effects of wakefield on the electron bunch: Transverse wakes

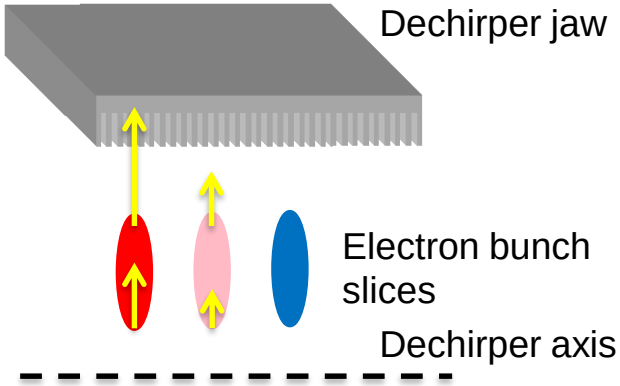
Time-Correlated transverse kick toward closer metal jaw



- Increases when jaw is moved closer to the bunch
- Used in the alignment procedure minimizing kick vs transverse offset of the structure
- Fine transverse alignment by minimizing orbit in the undulator with smallest gap available. (Better repeatability and control needed)



Time-Correlated defocusing



- Increases when jaw is moved closer to the bunch
- Larger effect with large transverse electron bunch at dechirper location.
- Can be cancelled by using two orthogonal dechirpers

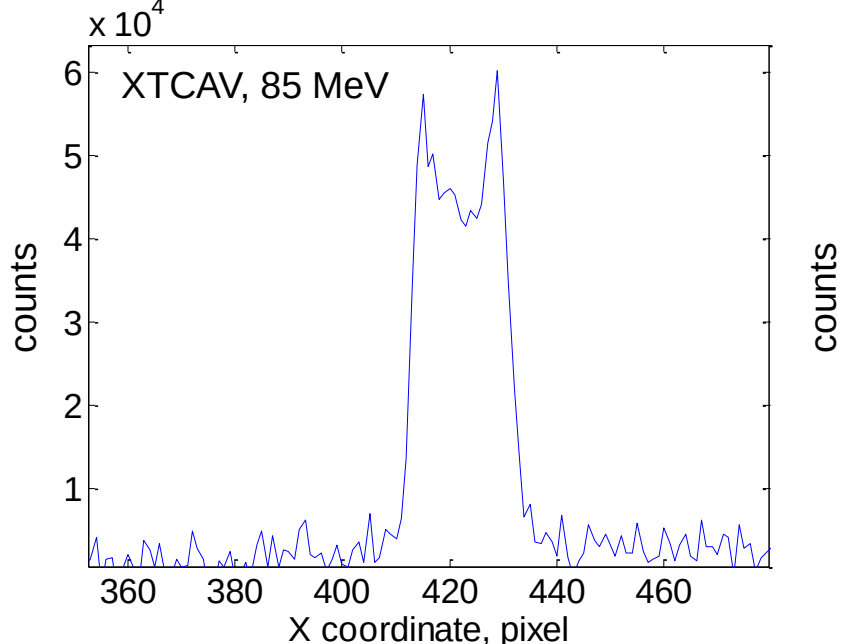
Transverse wakes: dechirper as passive streaker

- **Pioneer work:** Bettoni, S., Craievich, P., Lutman, A. & Pedrozzi, M., Phys. Rev. AB 19, 021304 (2016).
  First demonstration of a time-resolved measurement with a passive streaker
  Report of Referee B -- LJ15156/Bettoni - ***This article is about a gadget with very narrow applicability.***

- Novokhatski, A. Phys. Rev. ST Accel. Beams 18, 104402
  Attosecond resolution should be available with a long structure as the dechirper at high energies

- Craievich P. and Lutman A., *In press NIM A*, DOI 10.1016/j.nima.2016.10.010 (2016)
  Effects of the quadrupole wakefields in a passive streaker

- **Dechirper streaking shows more detail than X-band TCAV at 85 MV**



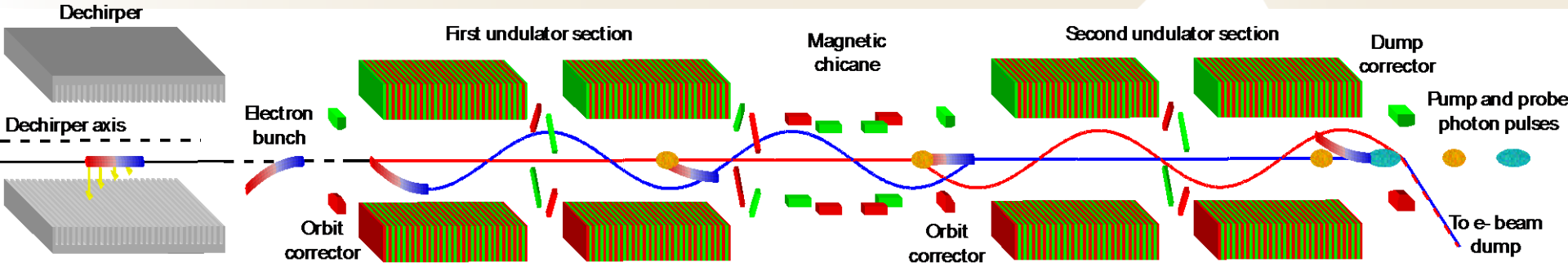
Horizontal dechirper
(raw data on screen)

250 μm
from beam

180 μm
from beam

14.5 GeV
4.5 kA
40 fs duration

Fresh-slice X-ray free-electron lasers

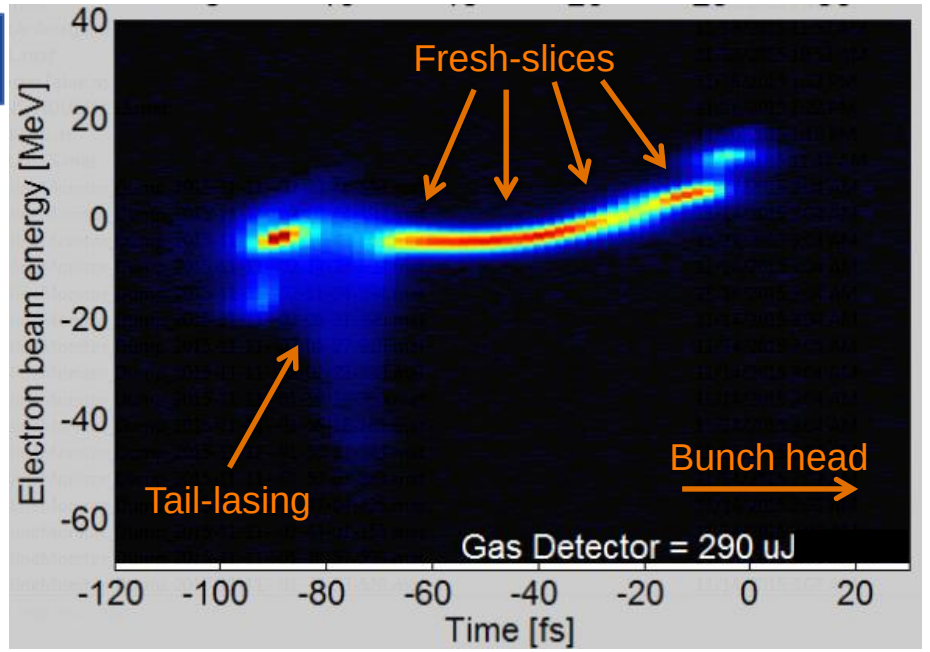


nature photonics
ARTICLES
PUBLISHED ONLINE: 24 OCTOBER 2016 | DOI: 10.1038/NPHOTON.2016.201

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]

- Fresh-slice allows one temporal slice to lase.
- Differently than with other schemes to achieve short pulses (slotted foil, low charge), non-lasing slices remain fresh and can still lase in downstream undulator sections



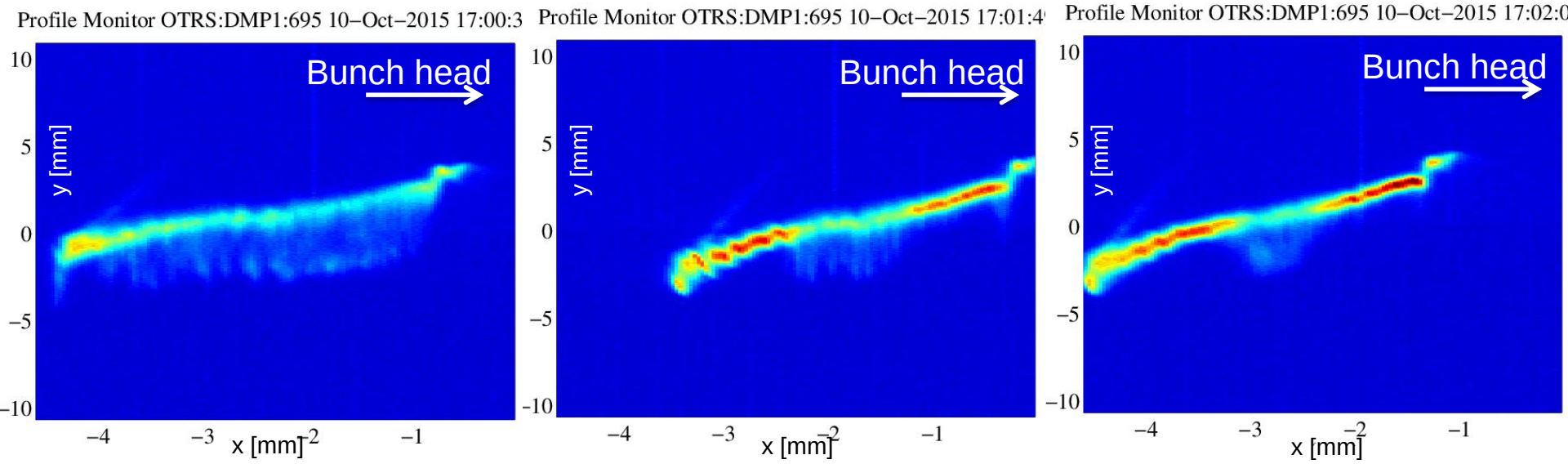
Concept developed independently at PSI

Prat, E., Löhl, F. and Reiche, S. *Phys. Rev. ST Accel. Beams* **18**, 100701 (2015). -> multi-stage amplification
Prat, E., Calvi, M. and Reiche,. *J. Synchrotron Radiat.* **23**, 874 - 879 (2016). -> wide bandwidth with transverse gradient undulator
Reiche, S. & Prat, E.. *J. Synchrotron Radiat.* **23**, 869 - 873 (2016). -> two-color scheme
Prat E., Bettoni S., and Reiche, S. *NIM A,* DOI: 10.1016/j.nima.2016.06.135 -> comparison of beam-tilting schemes

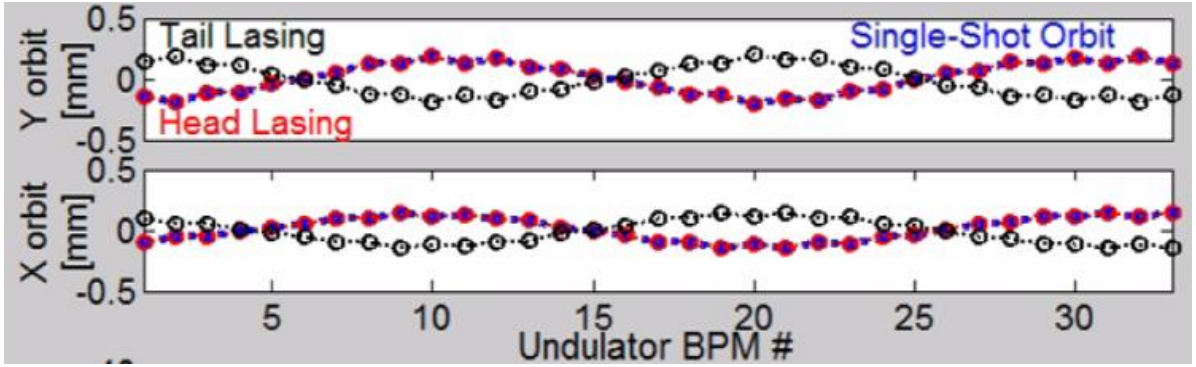
Fresh-slice X-ray free-electron lasers
Controlling the lasing slice

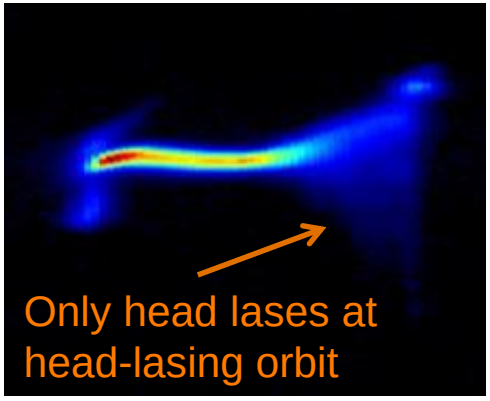
SLAC

- How it started: closing the gap to control the chirp, but the alignment must not have been good



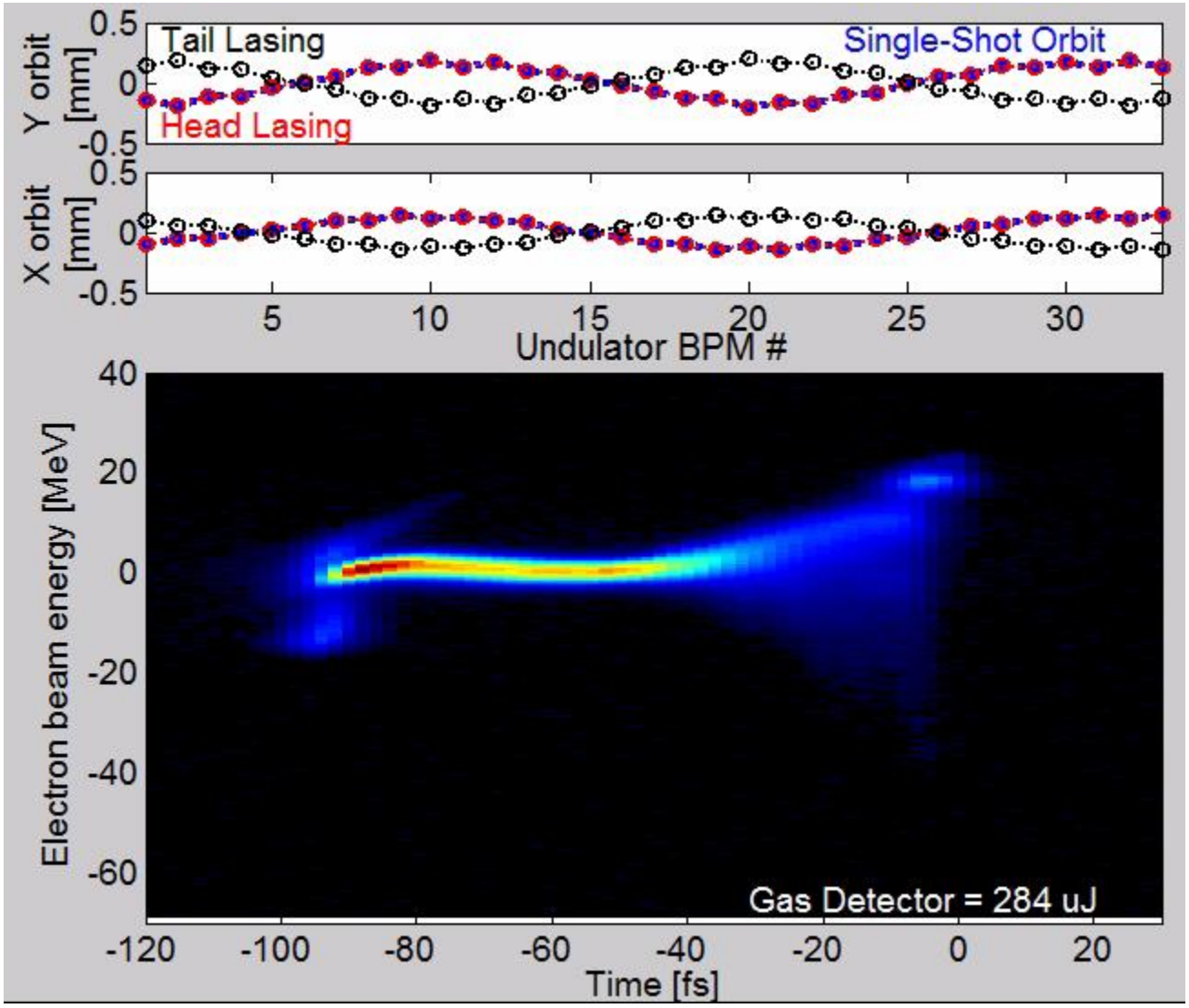
- Turn the **feedbacks off** and move the x-y jaws close to the beam to record **head lasing orbit**





Applications: Pulse duration control

Shorter pulses: (1) Increasing the dechirper offset or (2) Moving lasing slice toward far tail.



Both X and Y dechiper used

Recorded BPM orbits

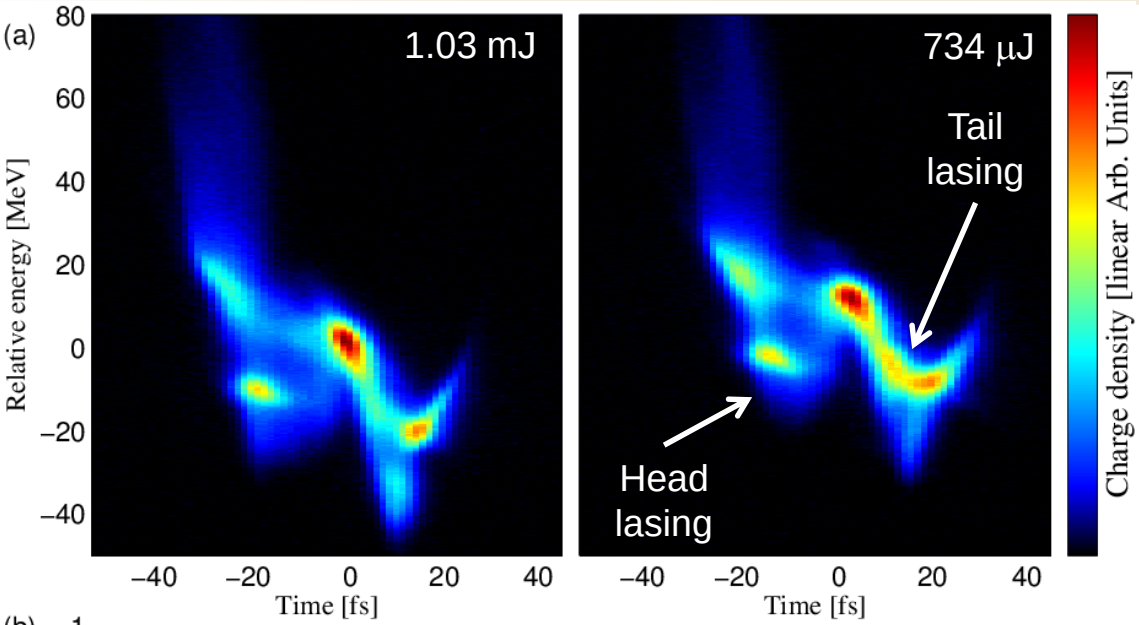
1.8 keV photons

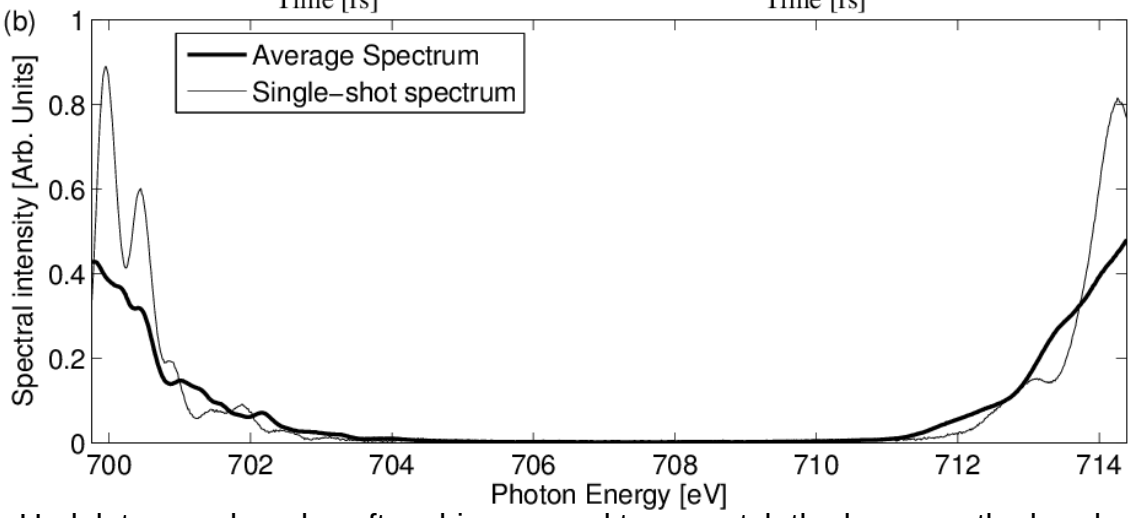
XTCAV images: electron bunch after lasing in undulator

Bunch head →

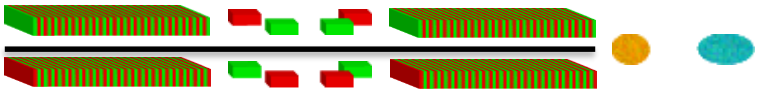
Applications: Two-colour beams

SLAC

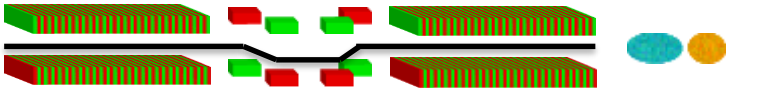




	Tail Pulse	Head Pulse
Energy [μJ]	248 ± 83	484 ± 91
Duration	~ 5 fs	~ 17 fs
Wavelength	715 eV	699 eV
Undulators	U1-U8, K~3.455	U26-U33, K~3.505



No chicane delay, pulse on head arrives first



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

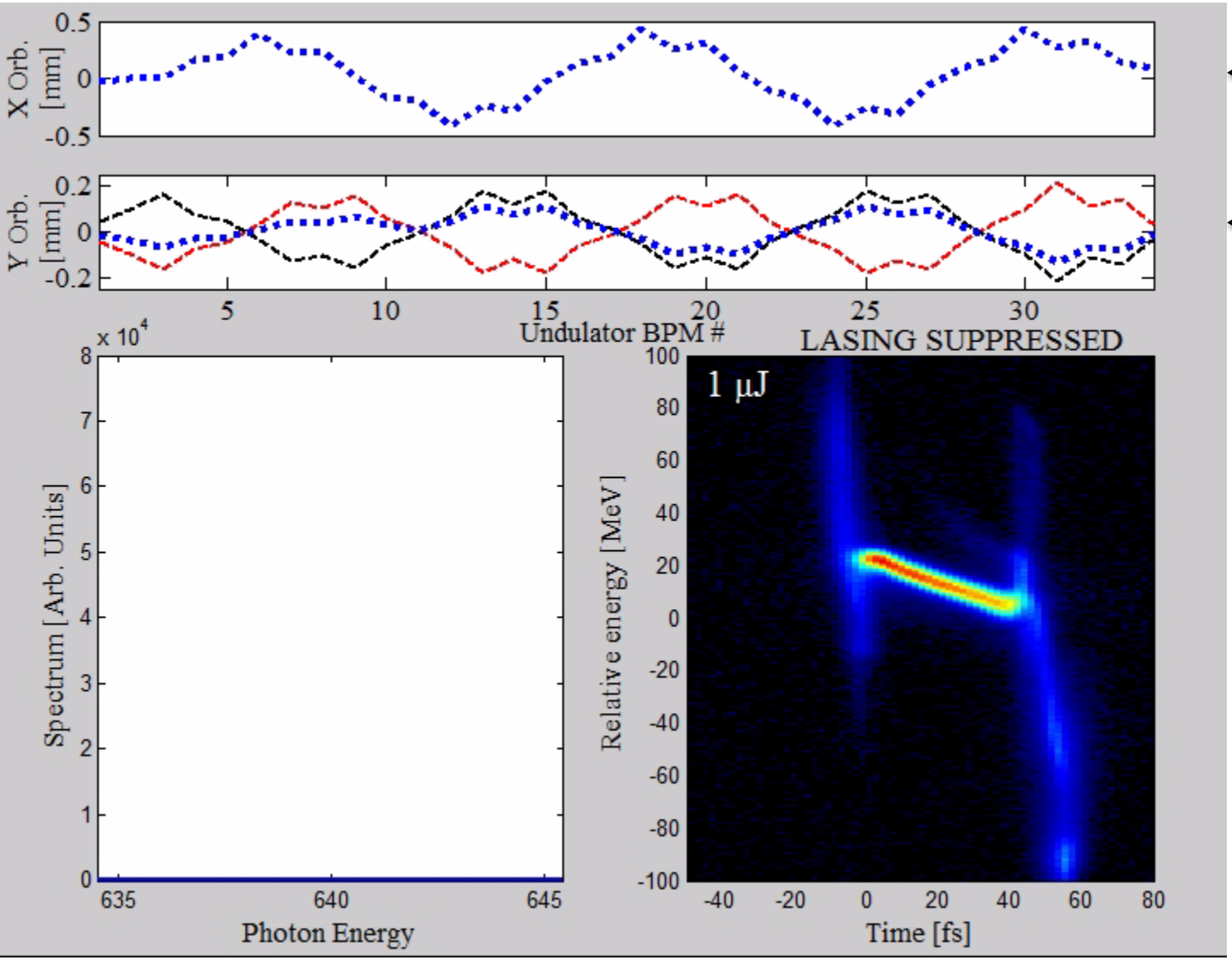
Scheme features:

+ Very easy to setup
+ Fully saturated short pulses
+ Delay controlled by chicane
+ Color separation controlled by undulator K
+ Scan through zero delay if tail lases first
+ Independent pointing in each section
+ Polarization control with Delta

Undulator quadrupoles after chicane used to re-match the beam on the head

A. A. Lutman *et al.*, Fresh-slice multicolour X-ray free-electron lasers, *Nature Photonics*, DOI 10.1038/NPHOTON.2016.201

Applications: Two-colour beams (Head lasing first yields more photons pump)



← X-orbit controls suppression in different sections

← Y-orbit controls lasing slice in each section

Larger pump with head lasing first, but can not temporally overlap the beams

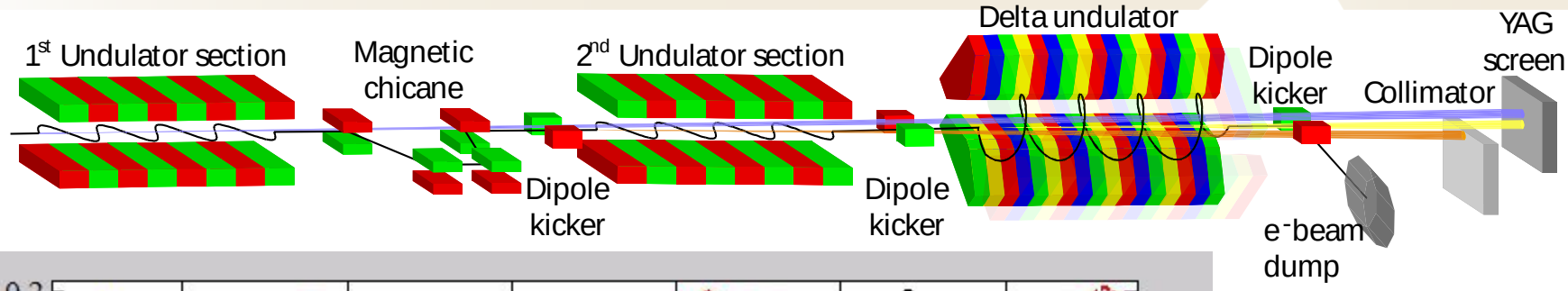
	Tail Pulse	Head Pulse
Energy	300 μJ	492 μJ
Duration	~10 fs	~20 fs
Ph. En.	638eV	642 eV
Und.	U1-U8	U16-U33

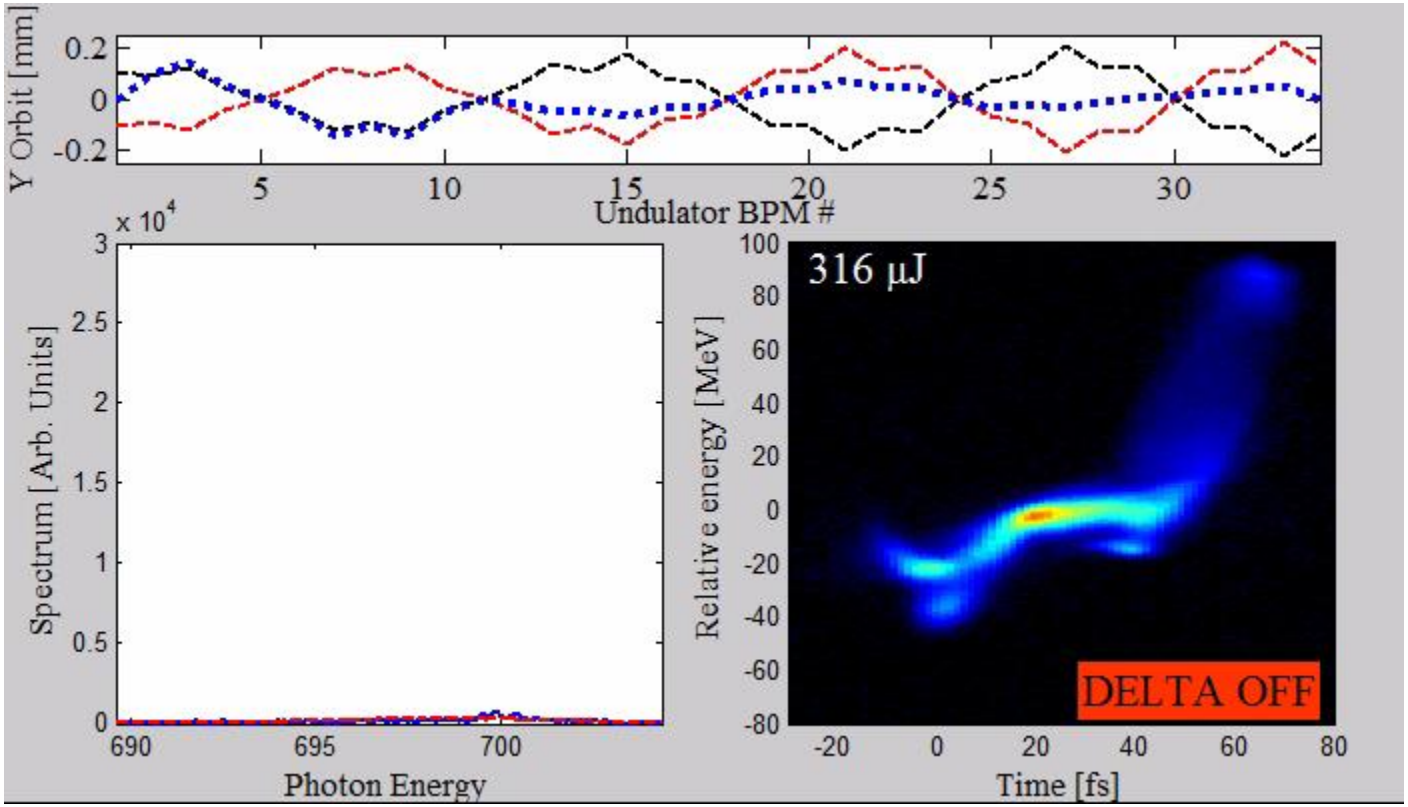
640 eV photons

Bunch head ←

A. A. Lutman *et al.,* Fresh-slice multicolour X-ray free-electron lasers, *Nature Photonics,* DOI 10.1038/NPHOTON.2016.201

Applications: Two-colour with polarization control





	Tail Pulse	Head Pulse
Energy	230 μJ	174 μJ
Duration	~5 fs	~17 fs
Photon En.	715eV	699 eV
Undulators	U1-U8	U26-U32 + Delta
Polarization	Linear	Circular

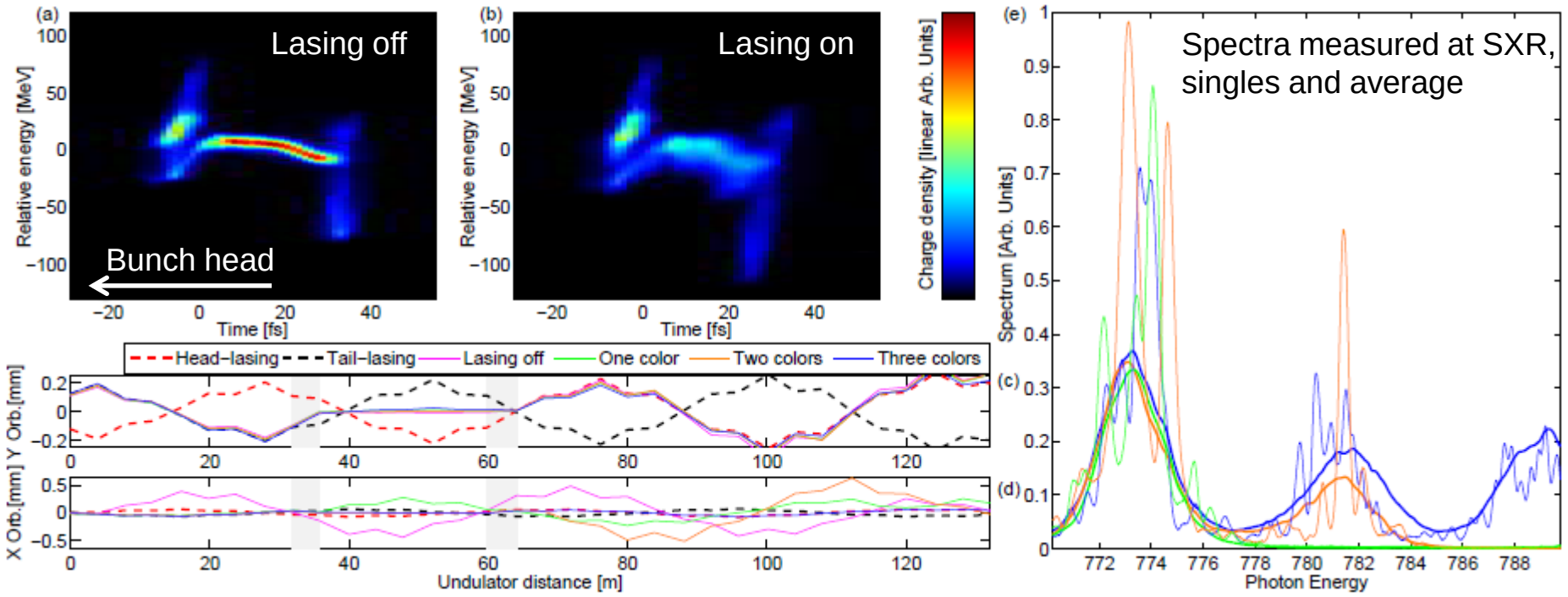
700 eV photons

Bunch head →

A. A. Lutman *et al.,* Fresh-slice multicolour X-ray free-electron lasers, *Nature Photonics,* DOI 10.1038/NPHOTON.2016.201

A. A. Lutman *et al.,* Polarization control in an X-ray free-electron laser, *Nature Photonics,* **10,** 468–472 (2016)

Applications: Three colours



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

A. A. Lutman *et al.,* Fresh-slice multicolour X-ray free-electron lasers, *Nature Photonics,* DOI 10.1038/NPHOTON.2016.201

Applications: 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, K. Fang, J. Wu, C. Pellegrini, “High efficiency, multi-terawattt x-ray free electron lasers”, PRAB 19, 020705 (2016)

C. Emma, A. Lutman, M. Guetg, J. Krzywinski, A. Marinelli, J. Wu and C. Pellegrini, Experimental demonstration of enhanced self-seeding in an X-ray free electron laser*, under review Phys. Rev. Lett.*

Final remarks

- Main limitation for amount of kick given are beam-trips in the LTU
  - Careful planning for beam and radiation losses is needed, especially for higher beam rates (LCLS-II, EuXFEL)
  - Using an active deflector looks scary (phase jitter experience with XTCAV, smaller deflecting strength than a passive device)
- A dechirper system X-Y is needed for quadrupole compensation
- Short gain-length is required
  - Plan for long undulator lines even at SXR, each section allowing for saturation and post-saturation taper.
  - Decrease gain-length:
    - eSASE (A. Zohlents Phys.Rev. ST AB **8**, 040701), (see XLEAP talk - Jerry Hastings)
    - Wakefield/Bunch compressor (S. Bettoni et al. Phys. Rev. ST AB 19, 050702)
    - Smaller emittance, also for soft X-rays, unlike we heard in previous talks !!
- Multi-stage schemes (Prat, E., Löhl, F. and Reiche, S. *Phys. Rev. ST Accel. Beams* **18**, 100701)**,** but also many other combinations will largely improve XFELs performance or enable new XFEL modes.
- Next generation of dechirpers should have better motion control and repeatability, beam position monitors at the device ends, ad hoc layout for proper optics control at the system entrance and exit.
- XTCAV needed for tuning (any mode will benefit, also regular SASE)
  (see XTCAV talk – Yuantao Ding)

Summary of Fresh-slice performance (SXR)

SLAC

Two-colour operation

Tail lasing first

Delay on soft chicane Small negative to 900 fs	Pump: Probe:	~5-8 fs ~5-20 fs	~100-250 μJ ~100-500 μJ
Delay on hard chicane Small negative to ~35 fs	Pump: Probe:	~5-8 fs ~5-20 fs	Never tried (~100-500 ?) μJ ~100-500 μJ

Head lasing first

Delay on soft chicane ~20 fs to 900 fs	Pump: Probe:	~20 fs ~10 fs	~ 500 μJ ~ 300 μJ
Delay on hard chicane ~20 fs to 70 fs	Pump: Probe:	~20 fs ~10 fs	~ 750 μJ ~ 300 μJ

Three-colour operation

Three short pulses (5-10 fs) with each (50-100 μJ)
Delay 900 fs between 1st and 2nd , 50 fs between 2nd and 3rd
Color separation limited by K, can do combo with beam chirp