X-Ray Laser-Enhanced Attosecond Pulses

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The Collaboration

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LCLS: A. Fry, S. Vetter, P. Hering, A. Miahanari, J. Hastings

PULSE: J. Cryan, P. Bucksbaum

ANL

A. Zholents, J. Xu

LCLS

SLAC NATIONAL ACCELERATOR LABORATORY

Sub-fs Science

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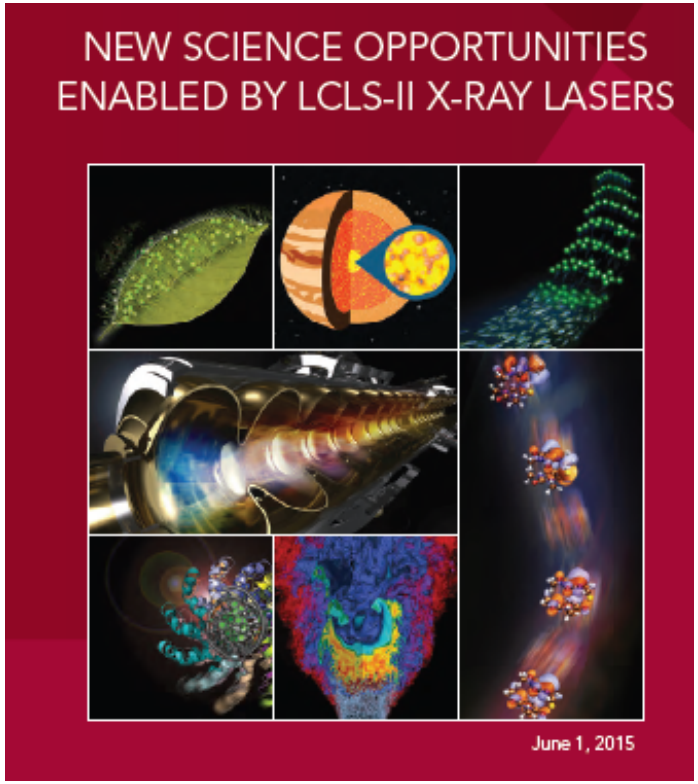


"Many of our great challenges in energy science, material science, and bioscience require new insights that lie beyond this femtosecond barrier…"

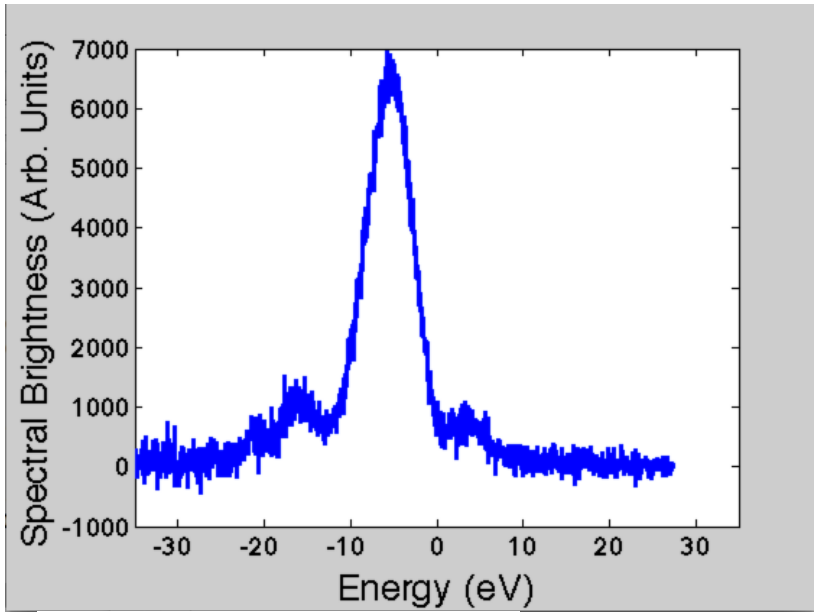
BESAC report, Nov 2015
Chapter 4

CHALLENGES AT THE FRONTIERS OF MATTER AND ENERGY:
Transformative Opportunities for Discovery Science

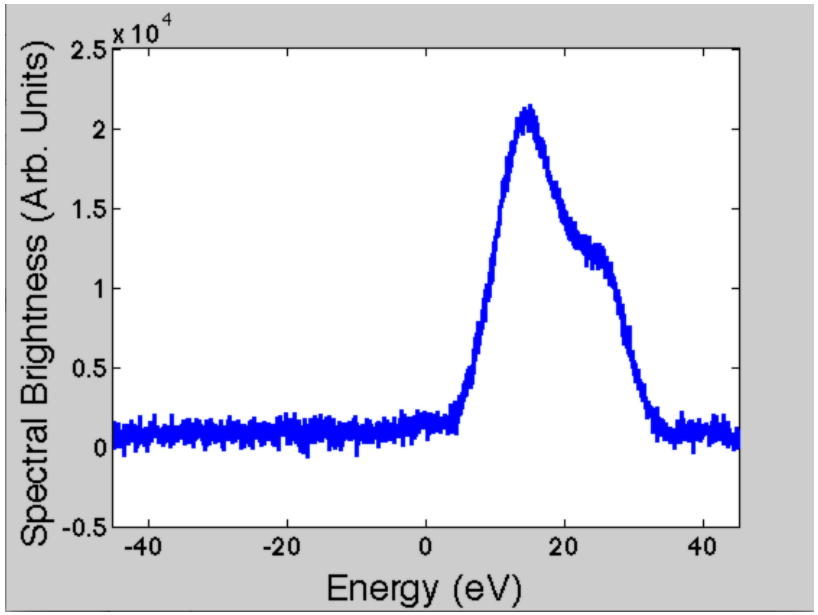
Further exploiting the degree of electronic coherence holds promise for the development of new energy technologies.

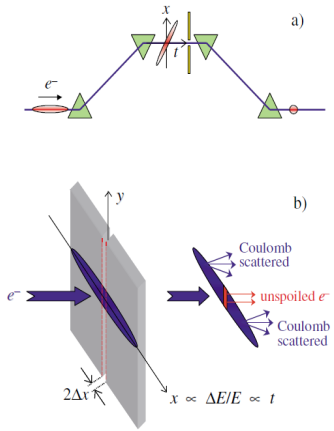
Attosecond Pulses at HXR

Good old slotted foil with modified optics



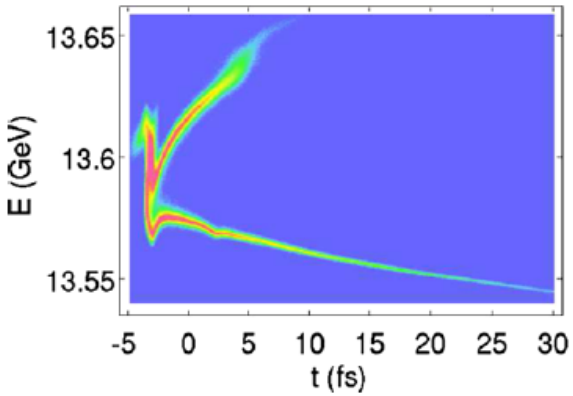
Nonlinear compression





Data @ 6 keV
Spike width
~4-7.5 eV (chirped)

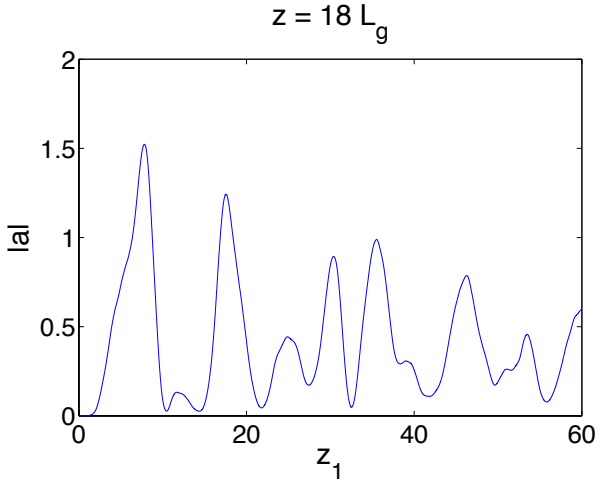
Pulse energy up to 10uJ
Mean ~5 uJ



What limits us at low photon energy?

The interest in sub-fs pulses is in the SXR region for ultrafast time-resolved spectroscopy. Requires ~3-5 eV of coherent bandwidth. However, typical single-spike duration is 1-2 fs at low energy…

Fundamental limit in FELs $\tau_{rms} \sim \lambda L_g/\lambda_u c$



VOLUME 73, NUMBER 1 PHYSICAL REVIEW LETTERS 4 JULY 1994

Spectrum, Temporal Structure, and Fluctuations in a High-Gain Free-Electron Laser Starting from Noise

R. Bonifacio,[1,2] L. De Salvo,[1] P. Pierini,[2] N. Piovella,[1] and C. Pellegrini[3]

At SXR energy typical spike length ~1-2 fs

Sub-fs pulse operation requires:

1) Sub-fs lasing bunch

2) Shorter gain-length!

Attosecond Slicing (ESASE)

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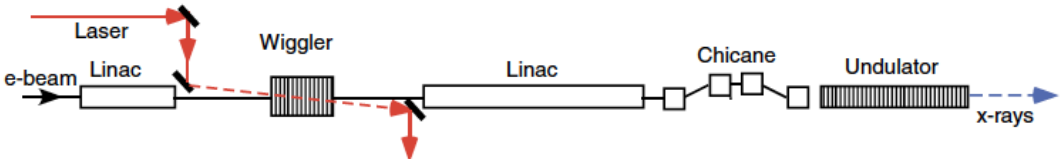
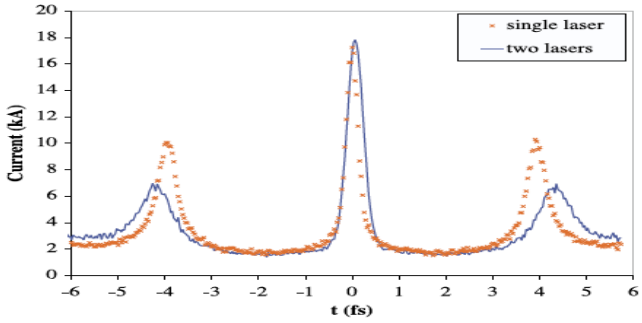
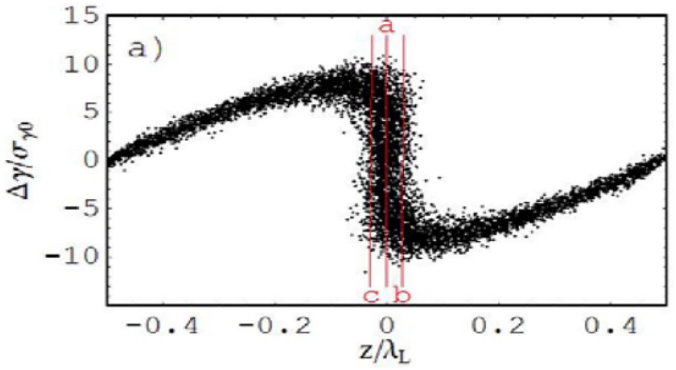
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 8, 040701 (2005)

Method of an enhanced self-amplified spontaneous emission for x-ray free electron lasers

Alexander A. Zholents





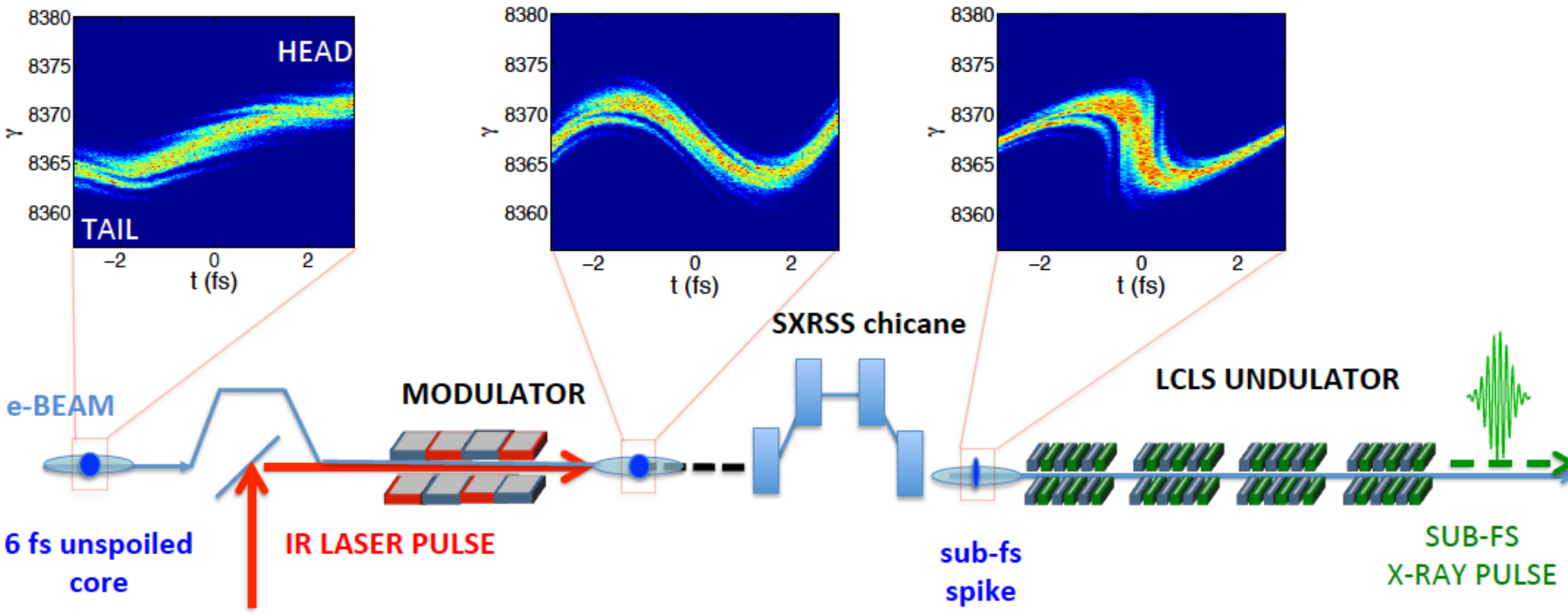


REMEMBER:
Short pulse operation requires:
1) Short lasing bunch
2) Short gain-length!

1) Short spike from laser (<< λ_l)

2) -Large compression in small chicane (no CSR)
-Compression right before undulator(less severe space-charge effects)

Proposed Scheme



Overcome jitter and difficulties associated with single-cycle laser:

- **Use a ps-long laser, λ = 2um**
- **6 fs lasing core (from spoiler or optical shaping) – matching the optical laser wavelength**

The XLEAP Project

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PROJECT SCOPE:

1) Ho:YLF laser from Q-peak delivers tens of mJ in 2 ps at λ=2μm.

2) SPPS wiggler refurbished by Argonne for interaction at 2 um. 6-period, variable gap, K up to 52!!

3) Build laser room and transport line to LTU.

4) User SXRSS chicane to compress.

PROJECT GOALS:

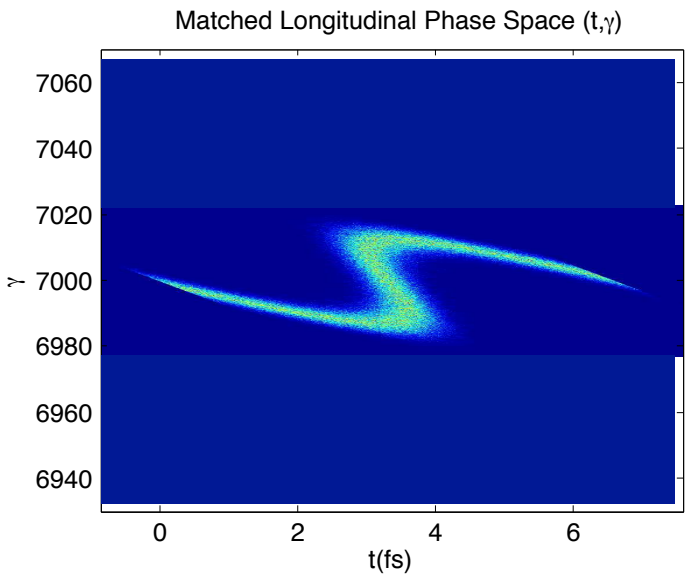
- generate sub-fs multi-eV (>3) pulses
- apply to two-color FELs for sub-fs pump/probe

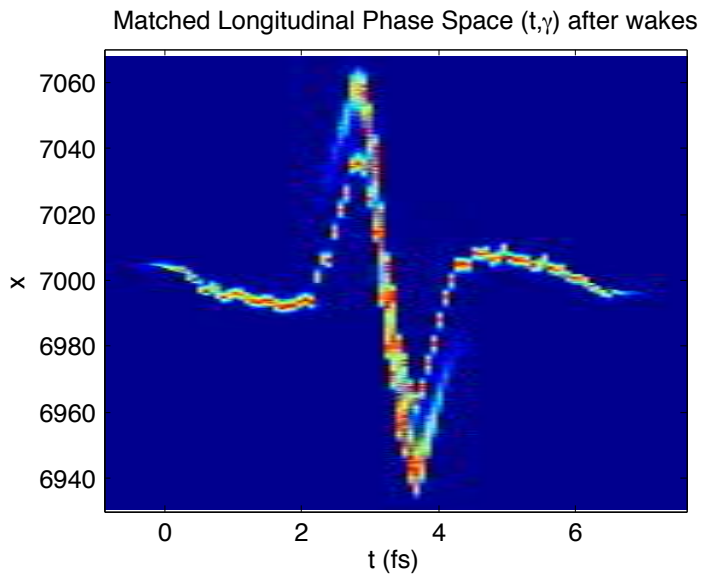
The XLEAP Project

- Passed CDR in February 16 and received final approval in May 16.
- 2.1 M$ over 3 years.

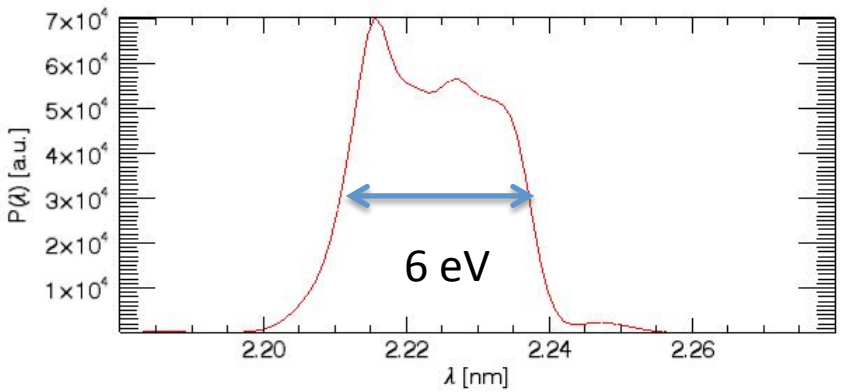
	FY16				FY17				FY18			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
-PURCHASE/TEST LASER. -TIMING HW.												
PROCUREMENT (EVERYTHING ELSE)												
INSTALLATION						1ST SHUTDOWN						
COMMISSIONING												
PROOF-OF-PRINCIPLE EXP												START 2ND SHUTDOWN

Chirp-Taper with Space-Charge

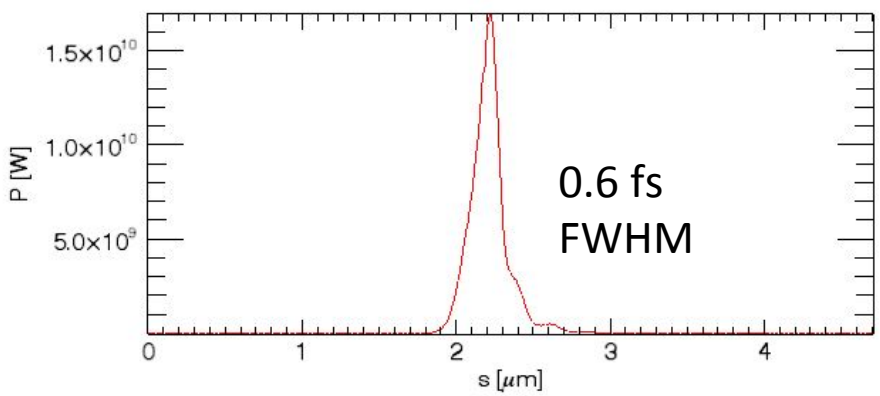




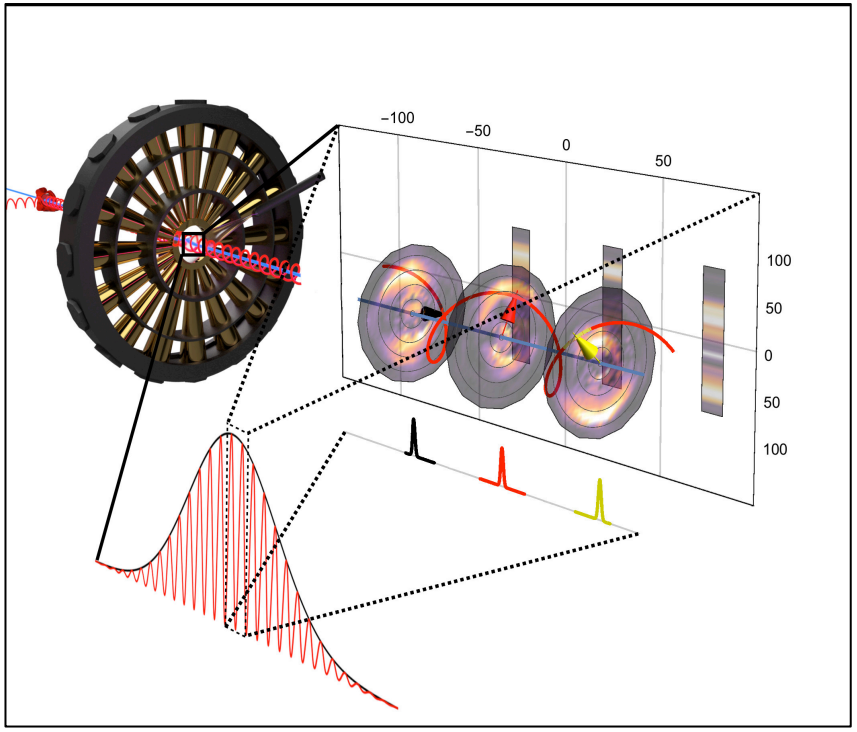
HUGE BANDWIDTH WHEN COMPENSATING CHIRP WITH TAPER! (Simulations at 520 eV)



Chirped sub-fs pulse



Pulse length measurement: Angular Streaking



Courtesy of N. Hartmann
To be published

Use IR circularly polarized laser to streak photo-electrons from XLEAP pulse.

Pulse duration << λ_{laser}
No need for ramped amplitude…

Angular width <-> pulse duration

Detection:
VMI + 2-D electron detector?
Cookiebox?

Sub-fs Pump/Probe with Two-Color XLEAP

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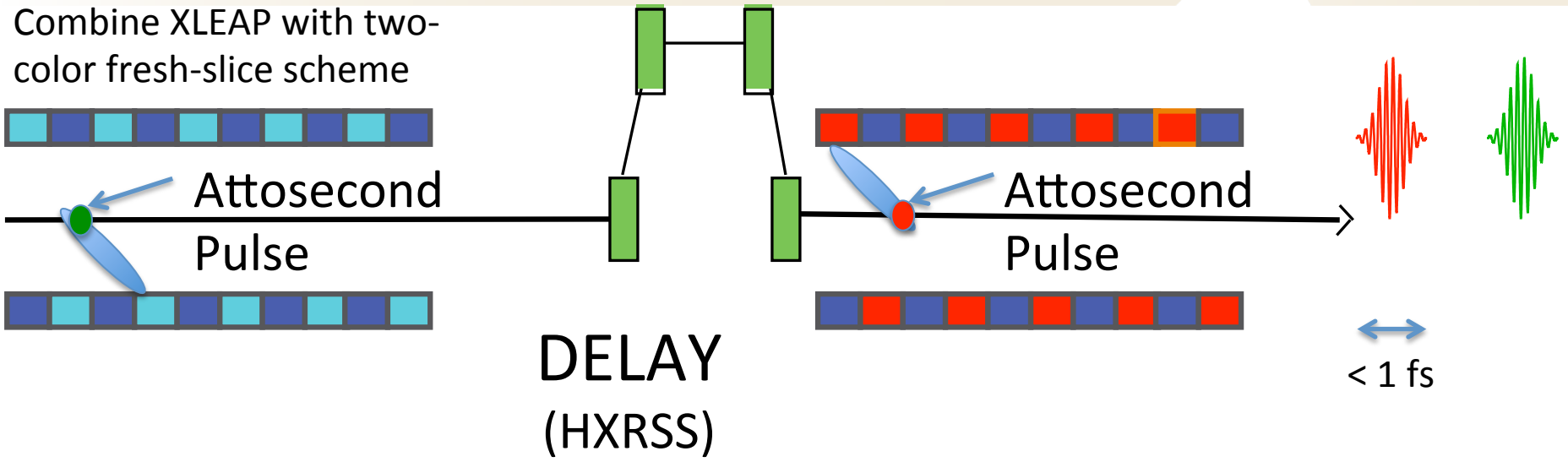
Combine XLEAP with two-color fresh-slice scheme

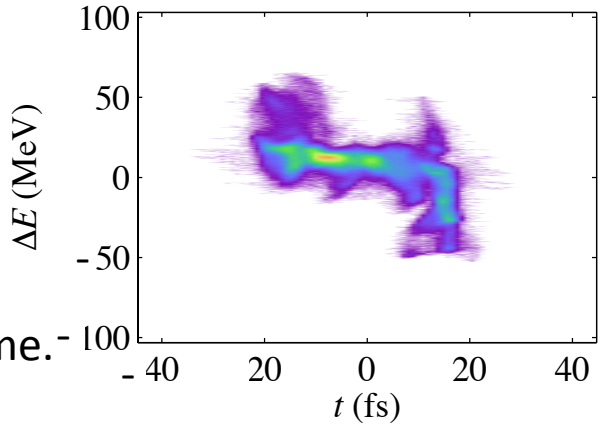


Delay between pulses locked by laser:

$$\Delta T = \Delta T_{CHICANE} + N\lambda_{LASER} + \text{Slippage}$$

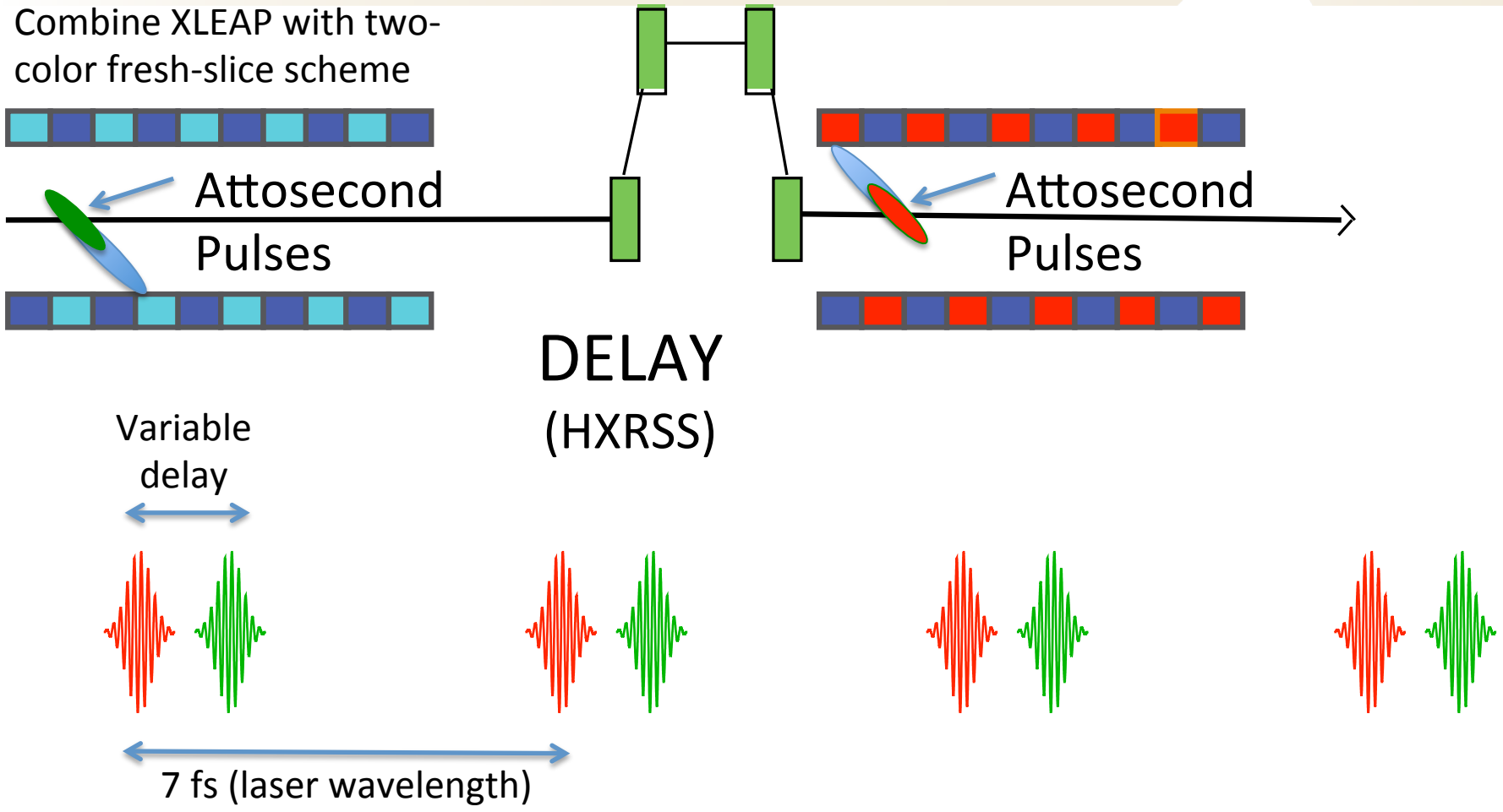
Two sub-fs pulses with sub-fs jitter!

Pump/Probe with sub-fs stability!



Two-color fresh-slice scheme.
See A. Lutman's talk

Double Pulse Train



STUDY SHORT-LIVED EXCITED STATES (E.G. CHARGE MIGRATION FROM CORE-EXCITED STATE)

Conclusions

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- XLEAP project approved and on its way.
- Installation during 6-month shutdown 2017
- Commissioning and proof-of-principle experiments in the following 12 months
- Goal: Sub-fs pulses with multi-eV bandwidth
- Path to sub-fs pump-probe using two-color in combination with XLEAP