Temporal and Spectral Shaping of X-ray Free-Electron Lasers

A. Marinelli

International Free-Electron Laser Conference
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8/21/2017

THANK YOU!

Thanks to all my friends and colleagues at SLAC, UCLA, Univ. of Rome and INFN

FEL physicists created a vibrant scientific community. Very positive exchange of idea and plenty of collaboration, even among “competitors”.
We are all lucky to be a part of it!

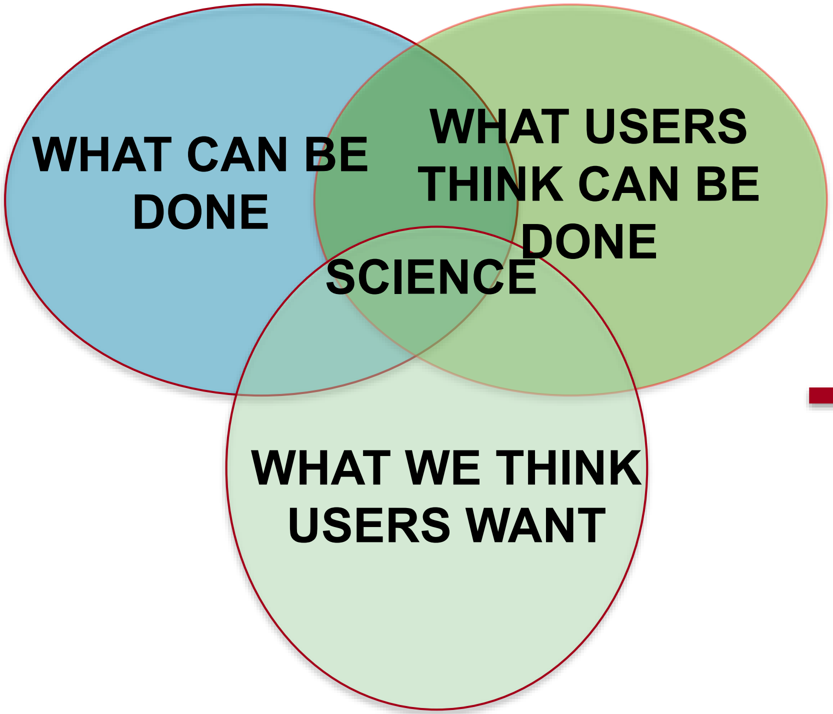
Outline

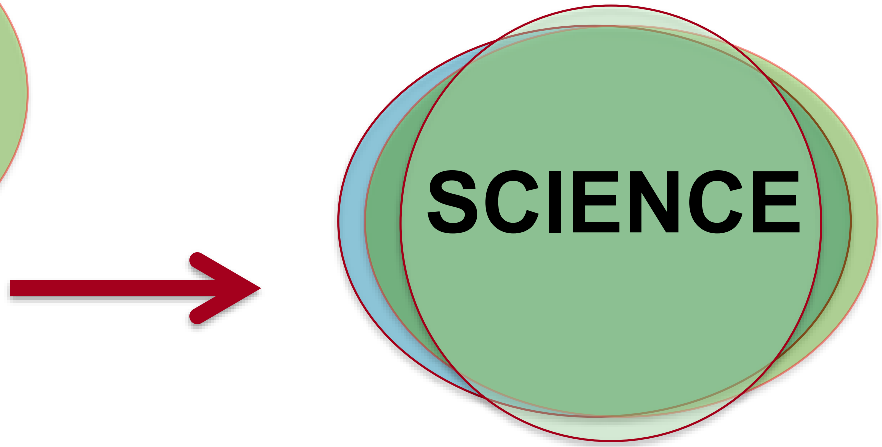
- Advanced FEL capabilities
- Two-colors
- Pulse duration control
- Towards attosecond science…

FEL R&D at LCLS

In its original design LCLS generates X-ray pulses with the following properties:

1) 500 eV to 10 keV Photon Energy
2) 30-100 GW Peak Power
3) 10-100 fs pulse duration
4) Coherence length << Pulse length
5) 0.1% Bandwidth





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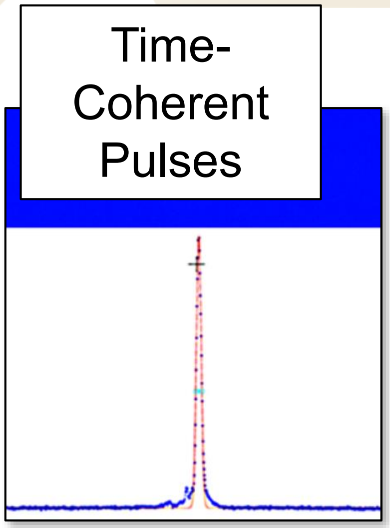

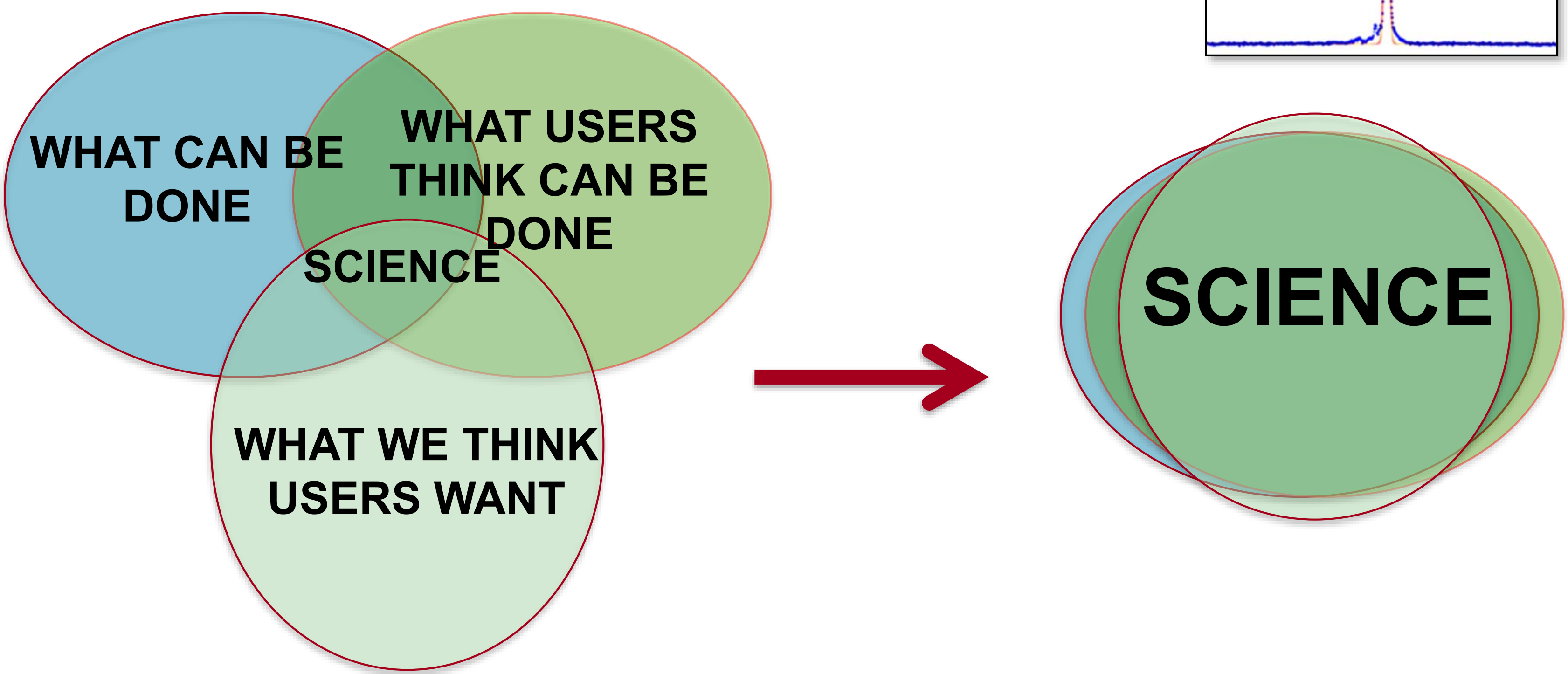

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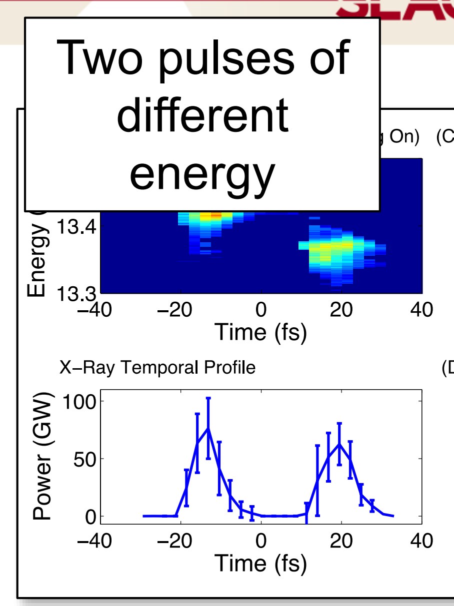

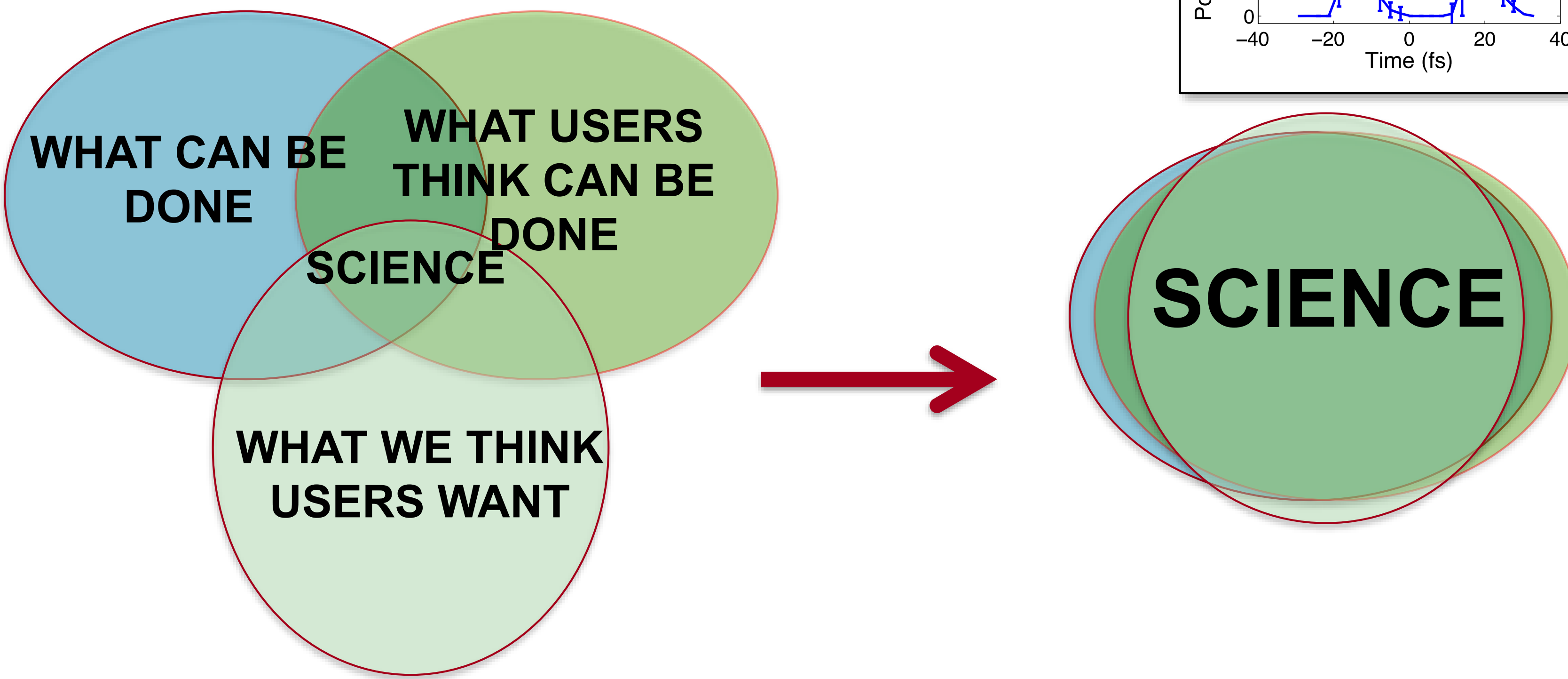

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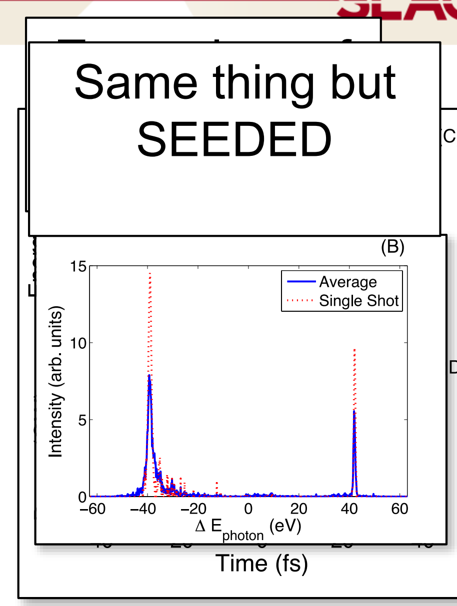

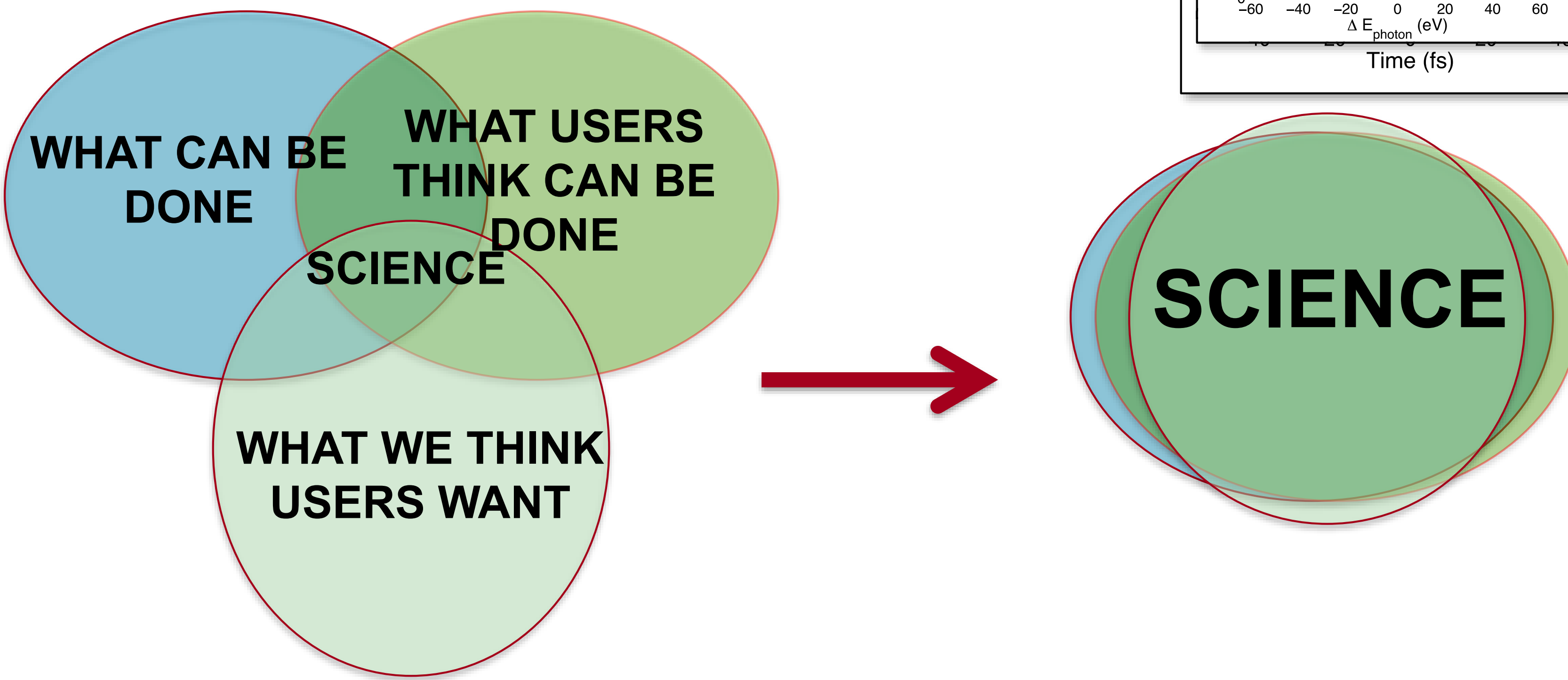

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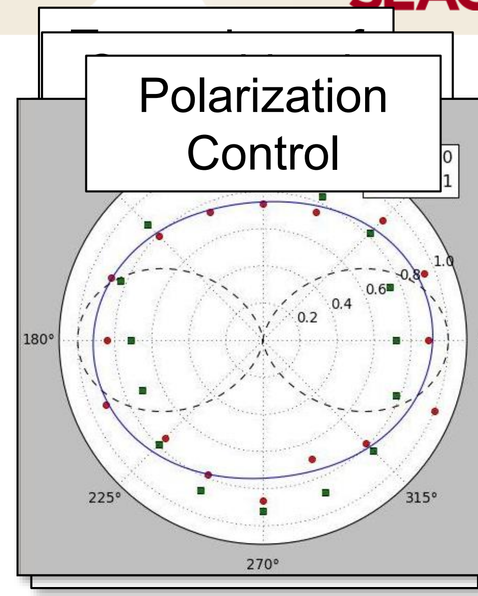
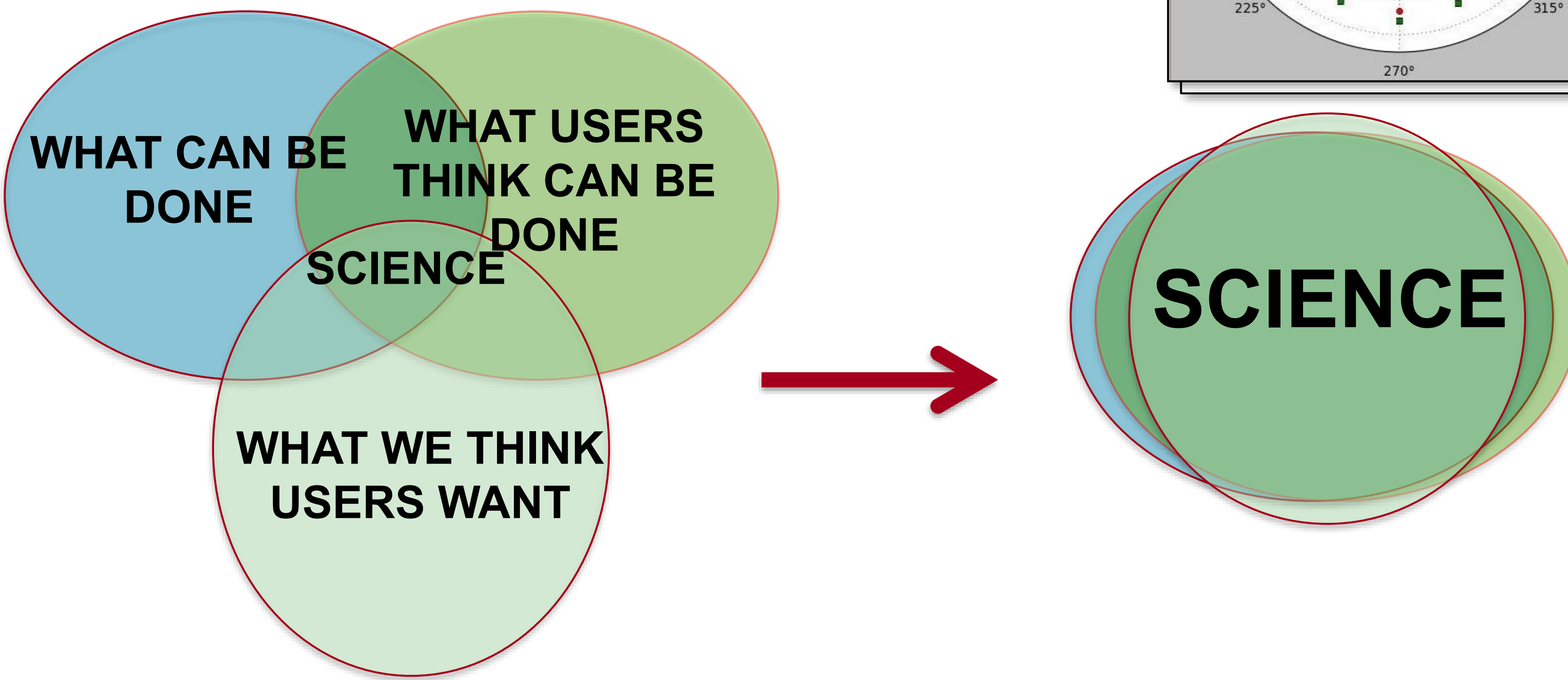


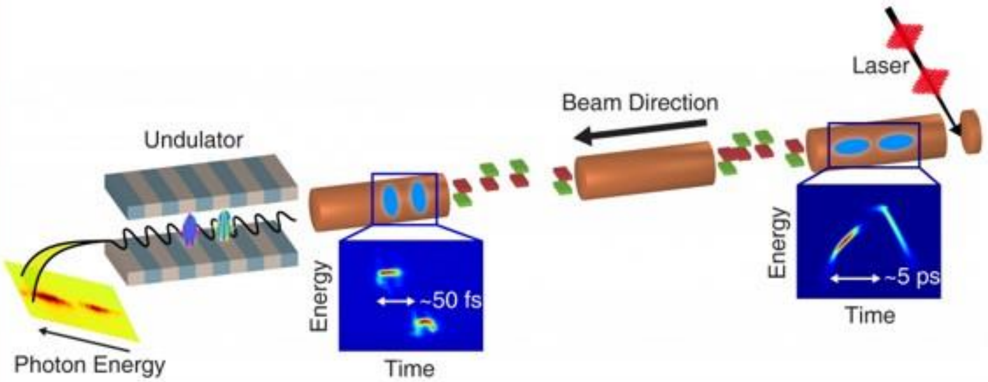


Two-Color FELs

SLAC

$$\lambda_{1,2} = \lambda_w \frac{1+K^2}{2\gamma_{1,2}^2}$$

- Double bunch at SPARC (V. Petrillo et al 2014)
- Twin bunch at LCLS (A. Marinelli et al. 2015)

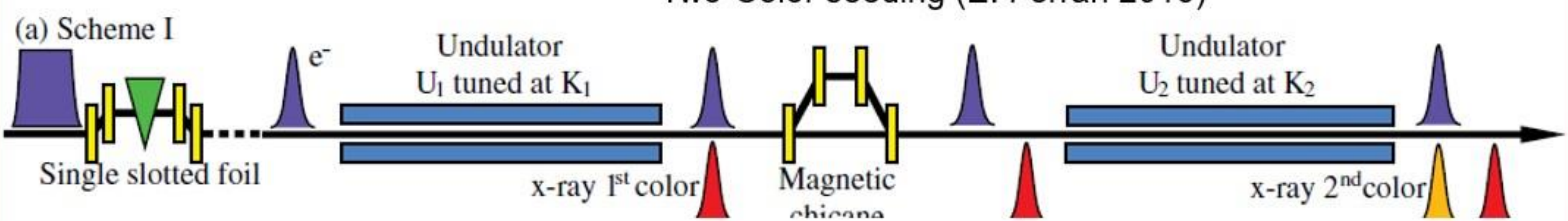


$$\lambda = \lambda_w \frac{1+K^2}{2\gamma^2}$$

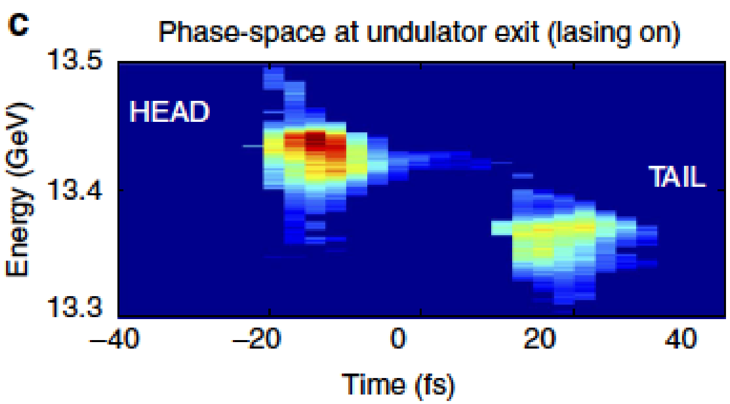
Two-color FELs fall into two different categories…

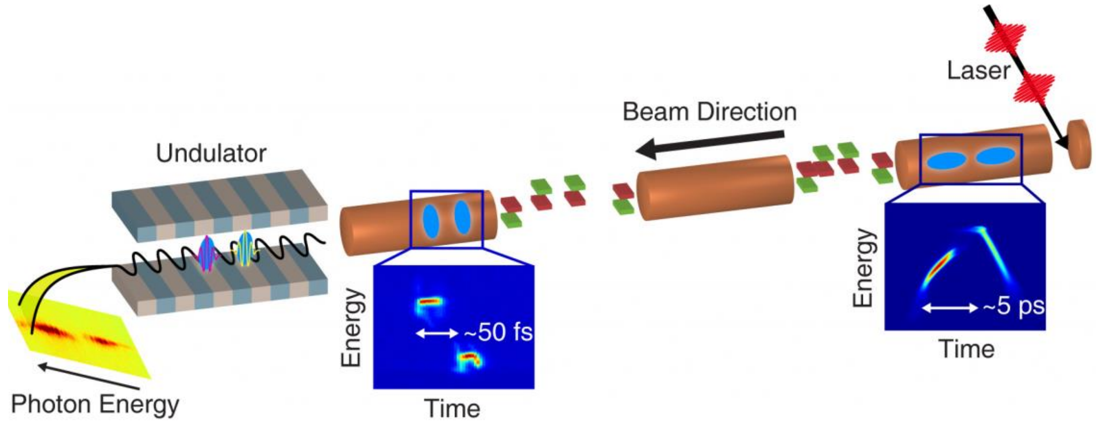
$$\lambda_{1,2} = \lambda_w \frac{1+K_{1,2}^2}{2\gamma^2}$$

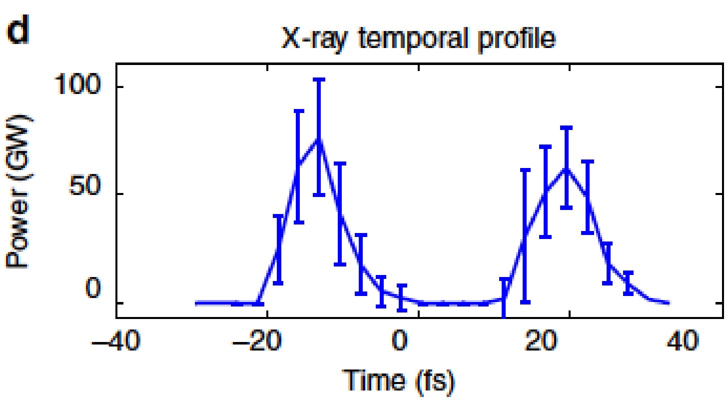
- Split Undulator (Lutman et al. 2013, Hara et al 2013)
- Gain Modulation (Marinelli et al. 2013)
- Fresh Slice (Lutman et al. 2016)
- Two-Color seeding (E. Ferrari 2016)



Twin-Bunch FEL





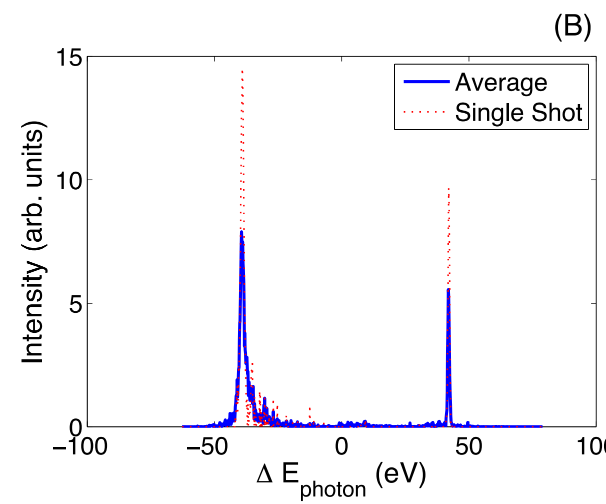


Peak power
~ 60 GW

Individual duration
dT = 10 fs

E_{pulse} = 1.2 mJ

DELAY UP TP 120fs



Allows 2-color seeding!

ARTICLE

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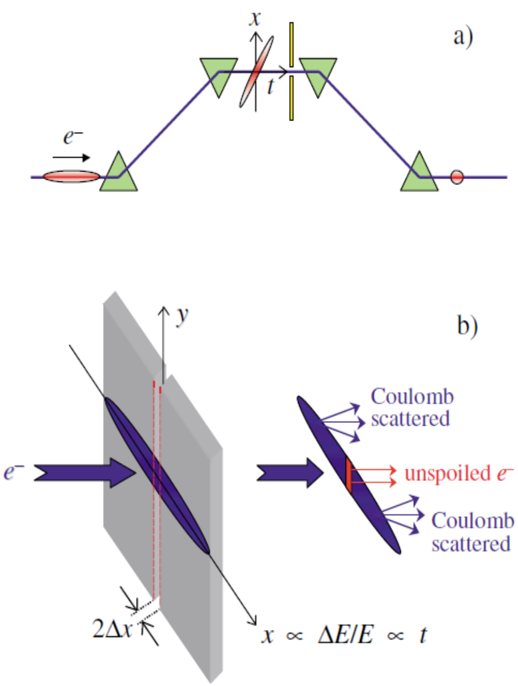
High-intensity double-pulse X-ray free-electron laser

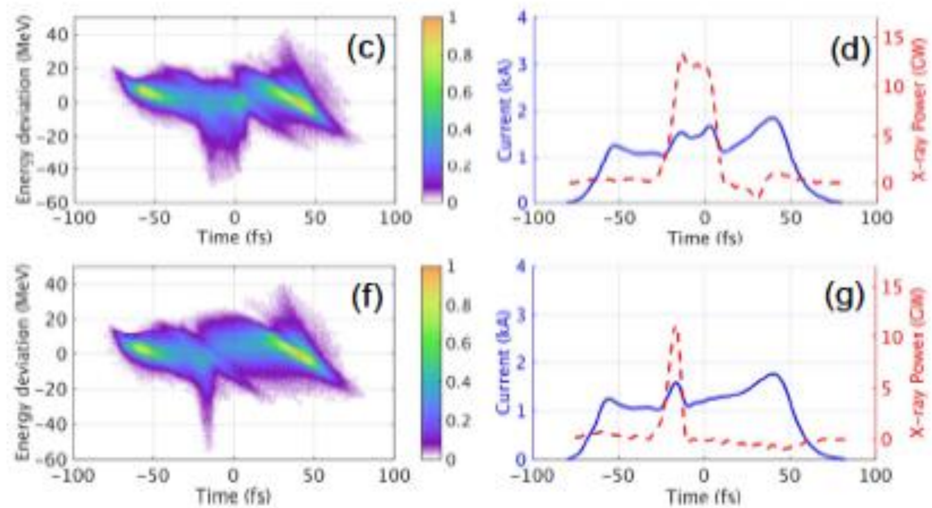
A. Marinelli[1], D. Ratner[1], A.A. Lutman[1], J. Turner[1], J. Welch[1], F.-J. Decker[1], H. Loos[1], C. Behrens[1,2], S. Gilevich[1], A.A. Miahnahri[1], S. Vetter[1], T.J. Maxwell[1], Y. Ding[1], R. Coffee[1], S. Wakatsuki[1,3] & Z. Huang[1]

Femtosecond Control of Pulse Duration

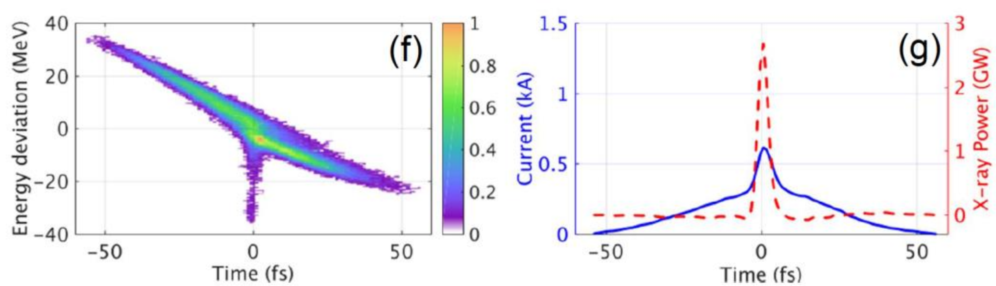
Emittance spoiler well established method for pulse duration control.



High charge-> min. pulse duration 10 fs

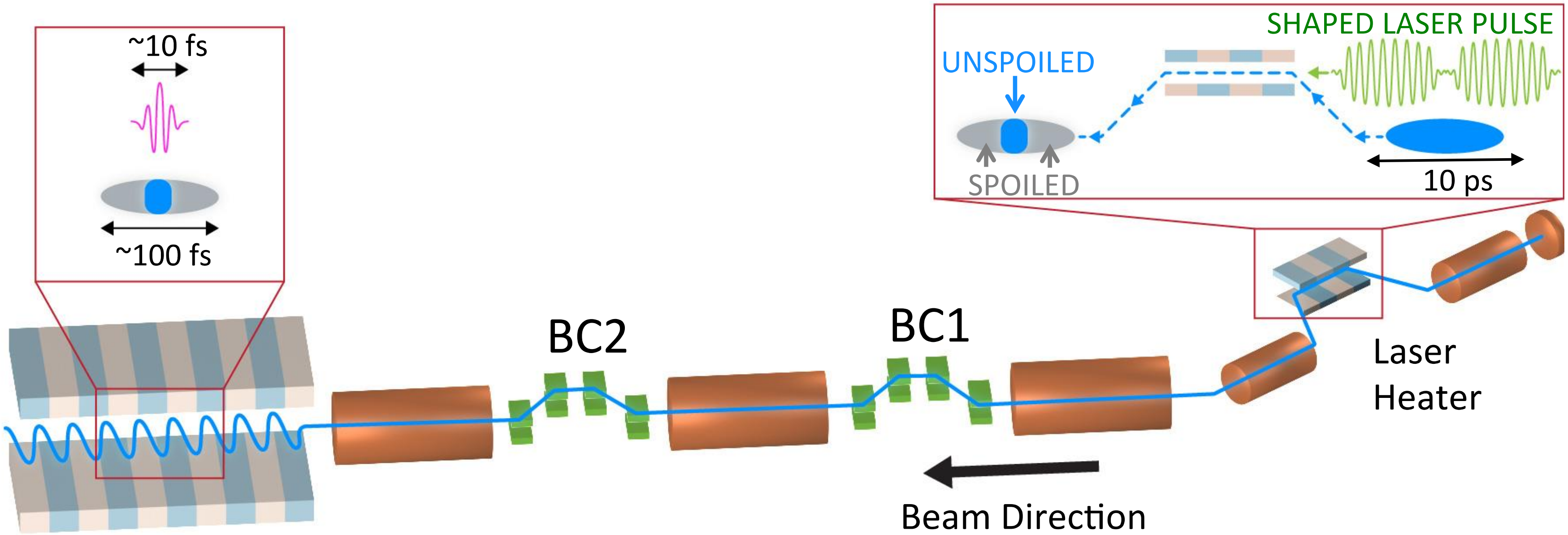


20 pC -> min. pulse duration 5 fs



Optical Shaping Experiment

SLAC



Coherent2 Heater Pulse
Ti:Sa λ = 760 nm
Bandwidth ~4 nm FWHM
Heater stretched to ~16 x Fourier limit
ΔT ~ 8 ps
ΔT_{coh} ~ 360 fs
Use DAZZLER to shape Heater


PRL 116, 254801 (2016) PHYSICAL REVIEW LETTERS week ending 24 JUNE 2016

Optical Shaping of X-Ray Free-Electron Lasers

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Optical Shaping Experiment

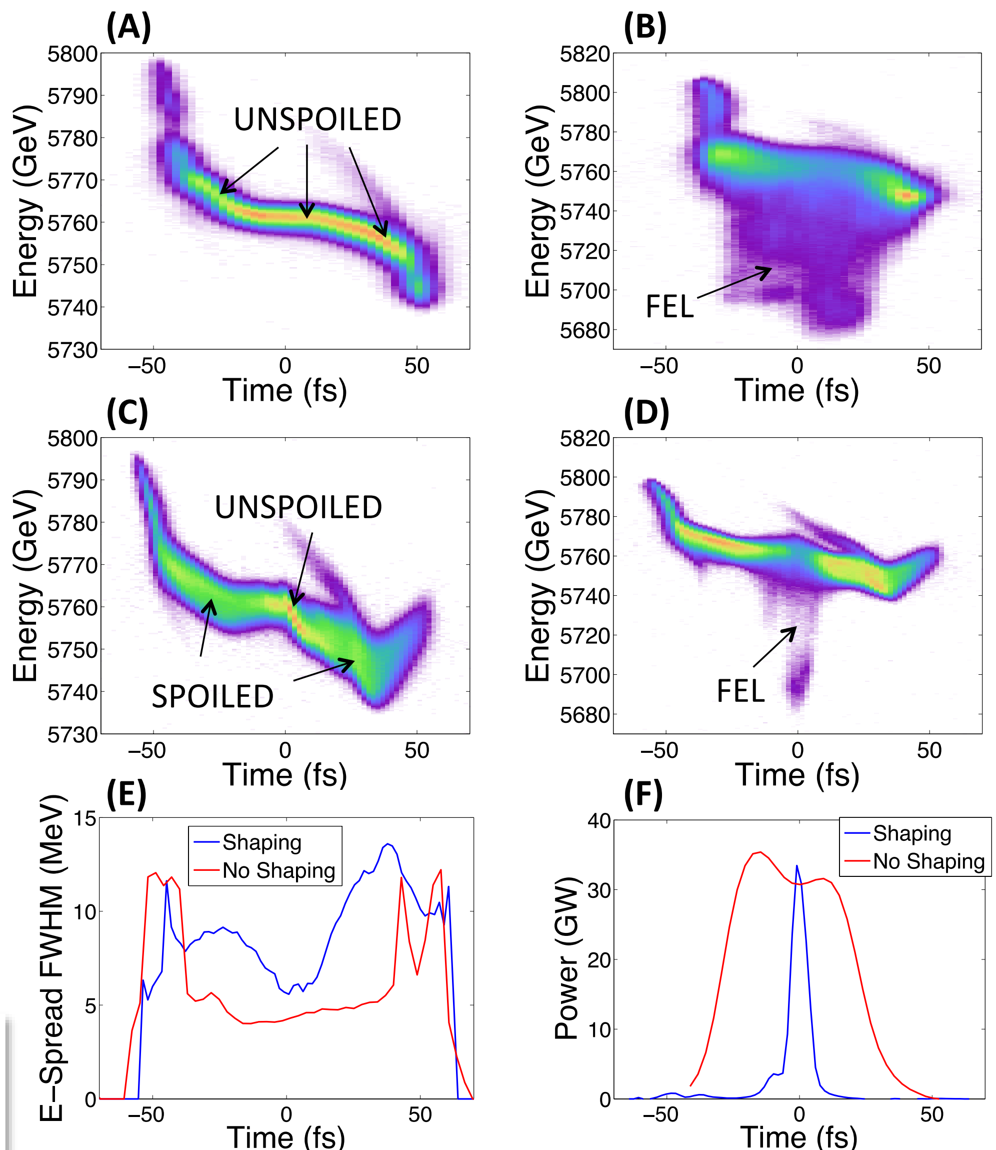
SLAC

Eph = 1.5 keV

Unspoiled Pulse: 55 fs FWHM

Shaped Pulse: 10 fs FWHM

FEL suppressed for
ΔE > 6 MeV FWHM



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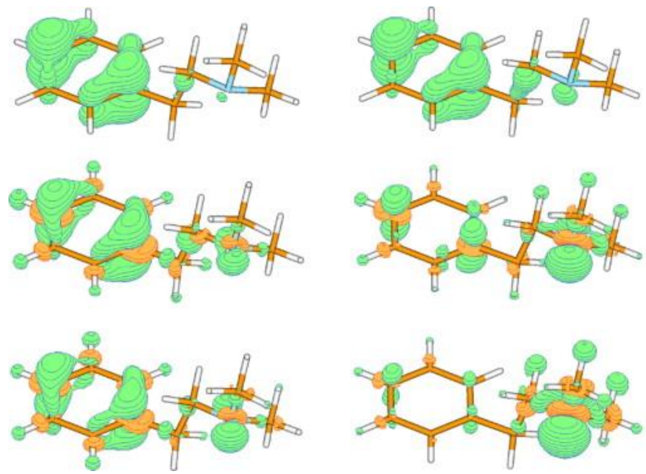
Motivation for sub-fs pulses

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

Charge migration: electrons can move across a molecule in less than 1 fs.

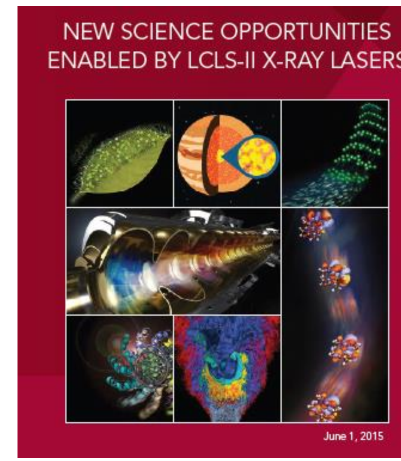


0 fs

2 fs

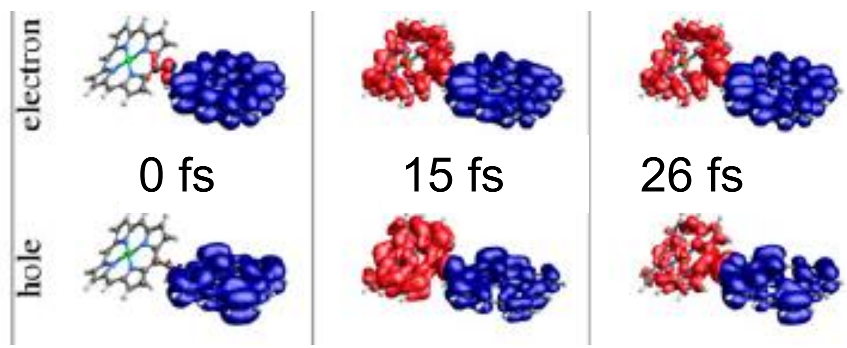
4 fs

From:



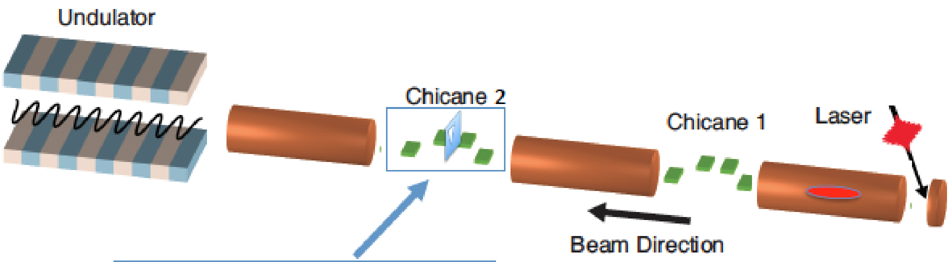
SLAC-R-1053

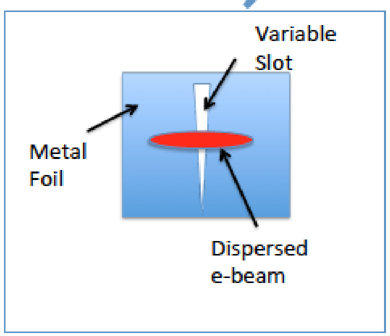
Stimulated x-ray Raman Redistribution: Coherent selective excitation and probe with sub-fs x-rays

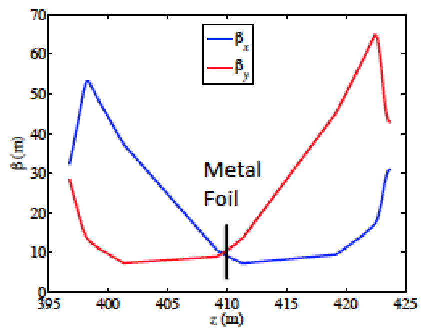


2015 BESAC report

“Single” Spike Operation at 6keV



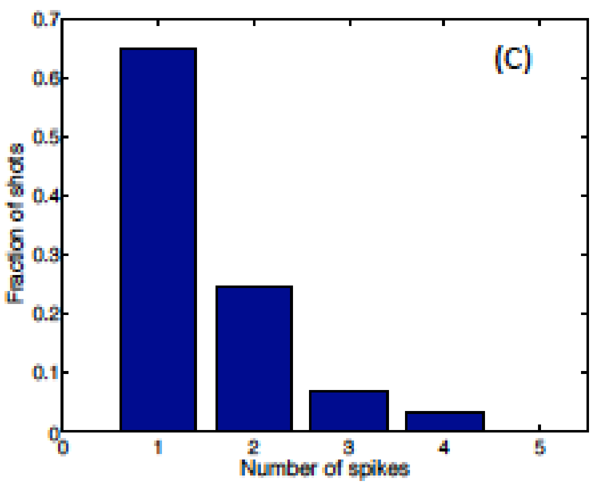


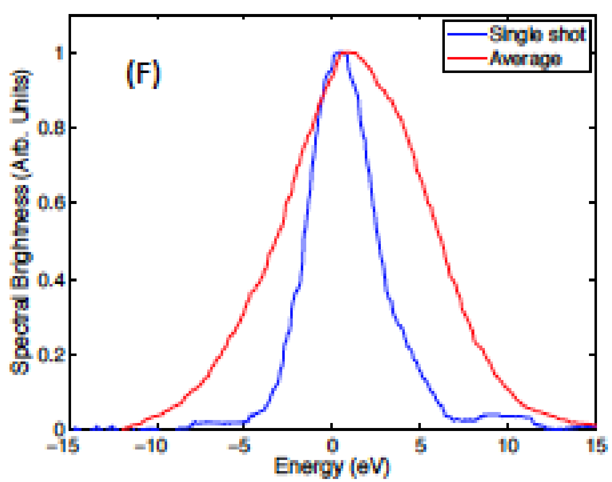


Limits of emittance spoiler:

1) Slot size
2) Undispersed size of the beam

Single spike limit can be achieves by modifying BC2 optics and using narrower slot!

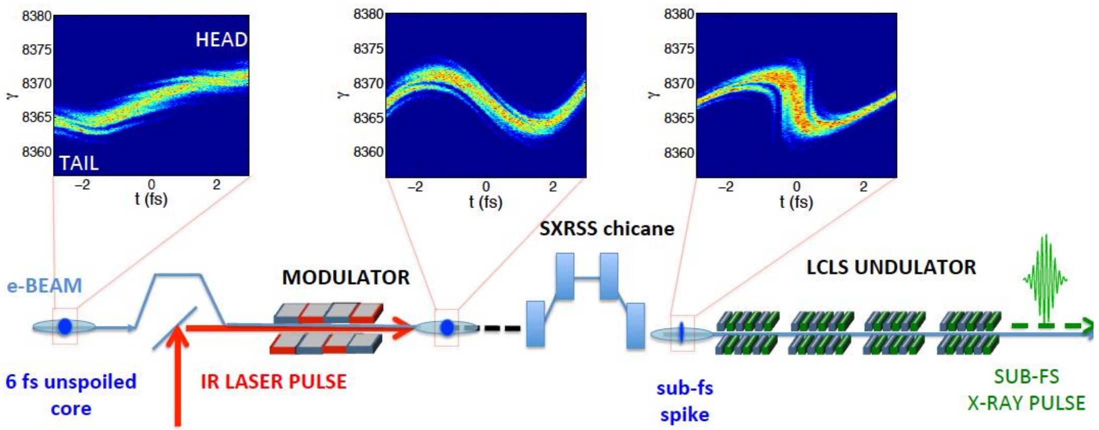




Output dominated by single-spike events.

BW ~ 4.5 eV
DT ~ 370 as

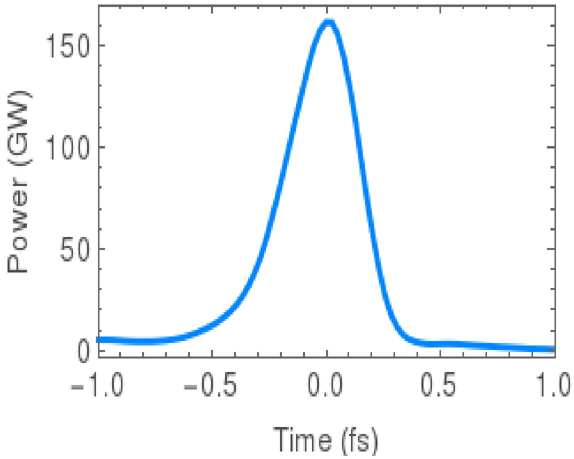
A Look at the Near Future…



All beamline components successfully commissioned. Ho:YLF Laser being tuned up to full power as we speak…

DT = 0.3-0.5 fs FWHM
Coherent bandwidth ~ 6-7 eV
Sufficient for impulsive Raman!

Collaboration among:
SLAC (AD, PULSE) and ANL



Summary

-Despite being a mature tool for science FELs are an exciting research field. LCLS R&D program has developed ~1-2 new capabilities every year.

-X-ray FEL properties can be tailored to the need of specific experiments. Lots of untapped potential in merging FEL R&D activities with user science.

-Two-color modes are now operational at LCLS (and other FEL facilities) and have delivered important scientific results.

-Laser-shaping important tool for pulse duration control at high-repetition rate FELs.

-Single-spike pulses at hard X-ray energies first step toward attosecond science at FEL facilities.

-Attosecond capability based on enhanced SASE and chirp/taper at soft-X-rays currently being commissioned.