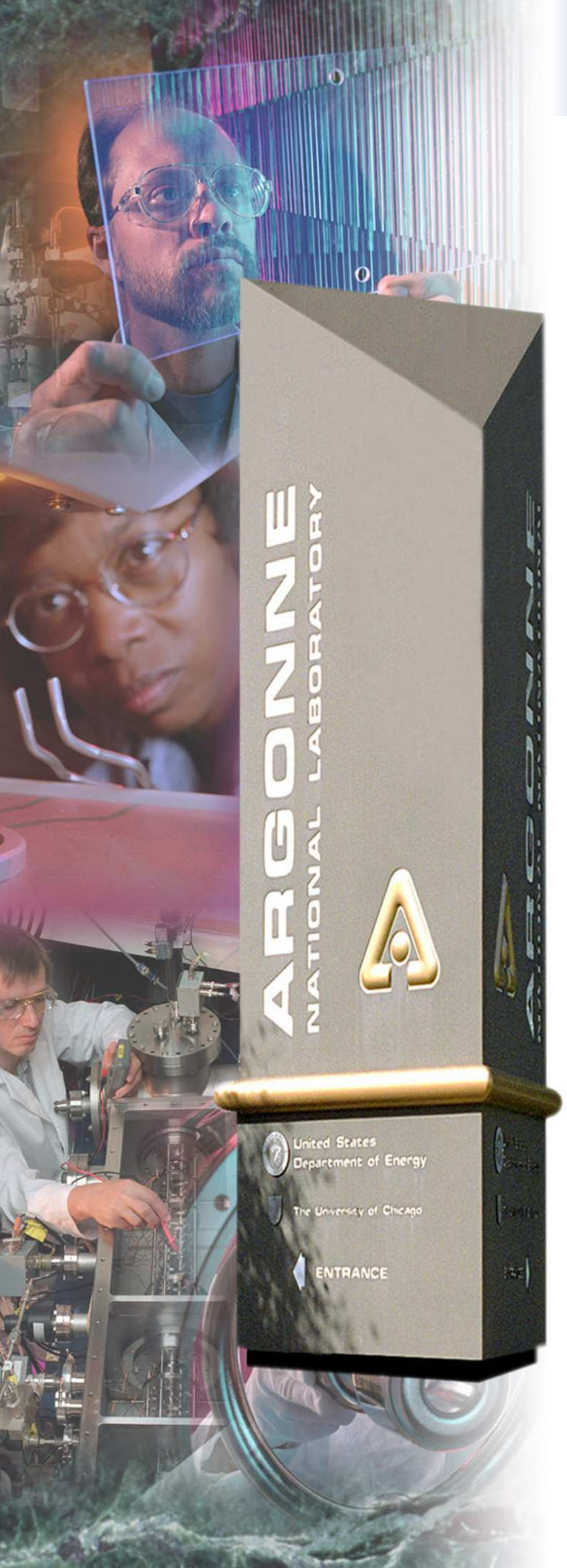

Visible/IR light and X-Rays in Femtosecond Synchronism from an X-Ray Free-Electron Laser

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APS, XOR

May 2006
FLS2006

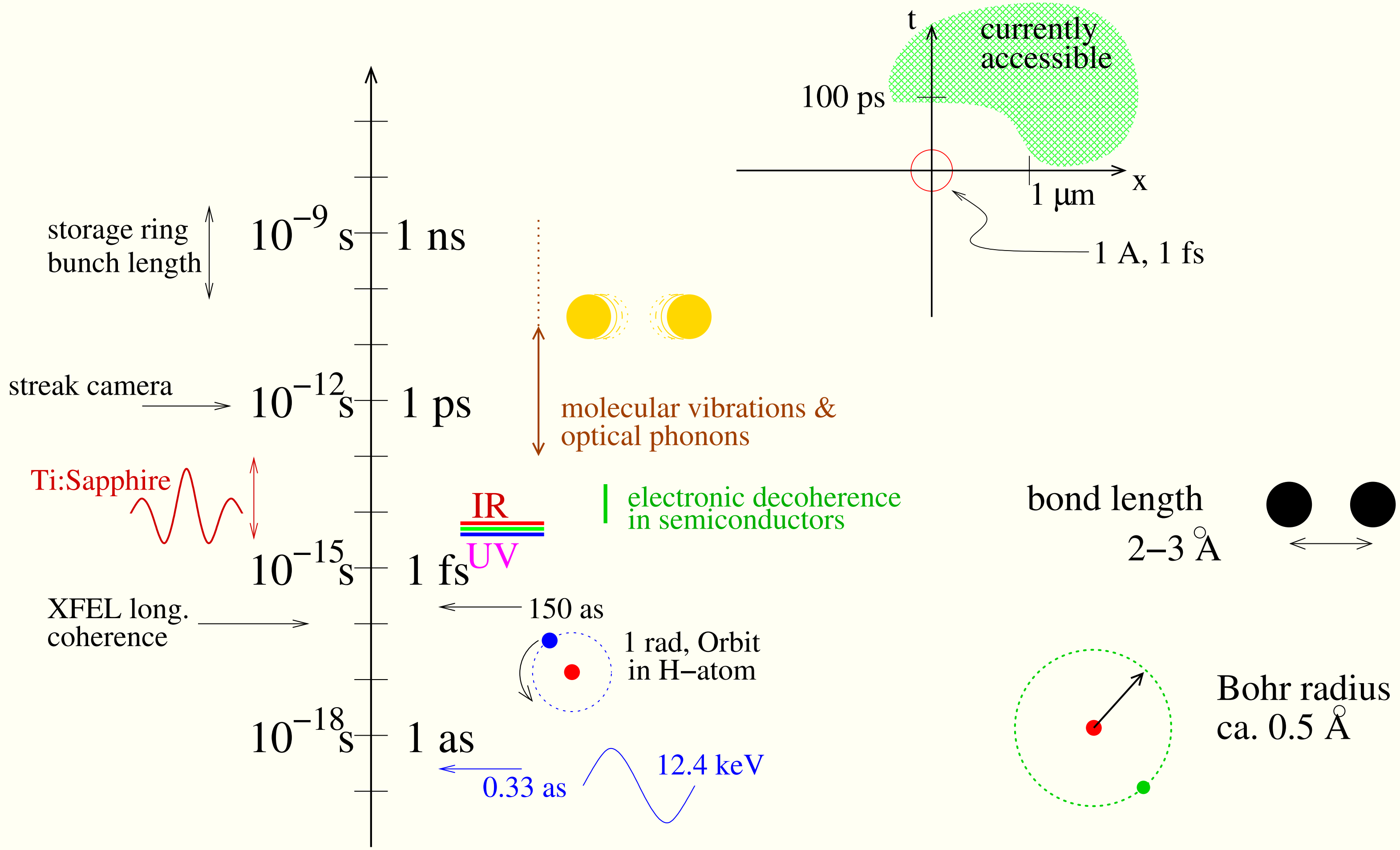
Argonne National Laboratory is managed by the University of Chicago for the U.S. Department of Energy

Topics

- Why few-fs x-rays?
- Emittance slicing for fs x-rays
- How to synchronize x-rays and light to a few fs
- TUR, CTUR
- Numbers
- Increasing emittance contrast
- Shaped scattering foil
- Boosting IR power using a laser amplifier

Valuable contributions from K.-J. Kim (ANL), P. Emma (SLAC), S. Reiche (UCLA), and P. Bolton (SLAC) are gratefully acknowledged. Funding: U.S. Dept. of Energy, Office of Basic Energy Sciences under contract no. W-31-109-ENG-38.

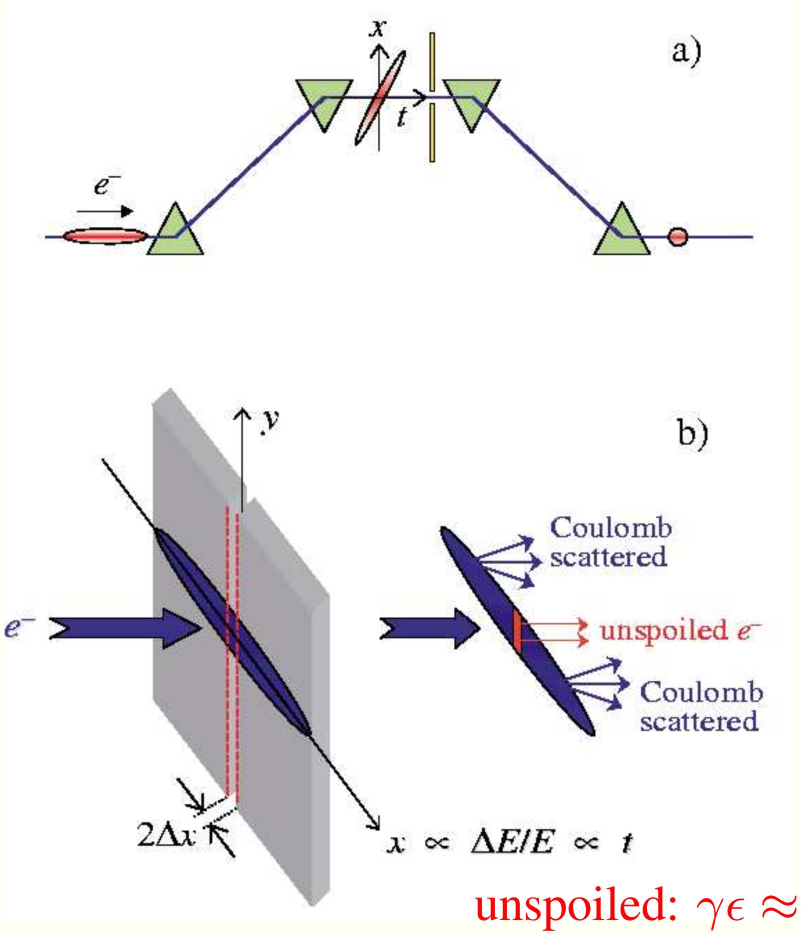
Elementary Processes in Chemistry and Solid-State Physics

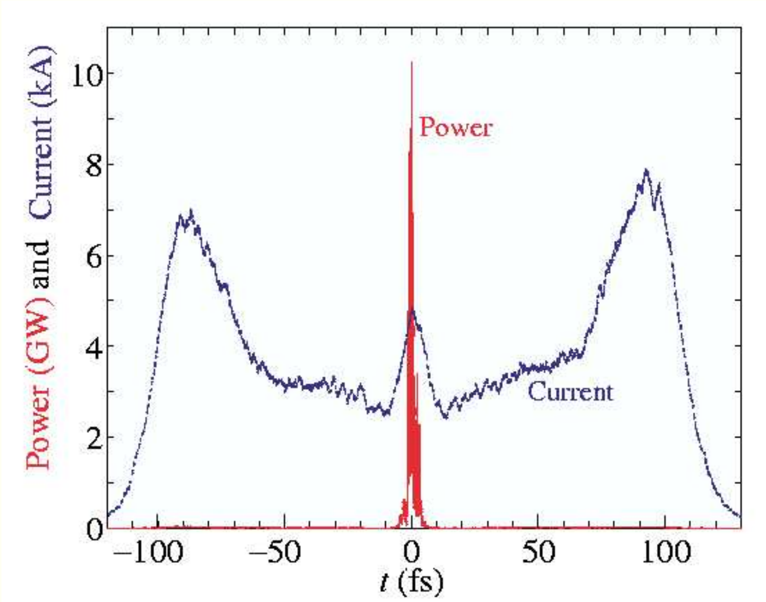


Light/X-Rays in Combination

- Energies: $\sim$ meV ... eV, lengths: $\sim$ nm, times: $\sim$ fs ... ns
- Light: eV directly, meV via Raman processes, relaxation
- X-rays: 10^{-2} nm ... 1 nm: scattering, atom positions through element-specific spectroscopy
- Short-pulse laser: fs ... ps, synchrotron: $\sim$5 ps ... 100 ps, linac: 100 fs ... 100 ps, soon a few fs, possibly 0.1 fs

Emittance Slicing





few-fs SASE emission

unspoiled: $\gamma\epsilon \approx 1\mu$m

spoiled: $\gamma\epsilon \approx 5\mu$m

P. Emma et al., PRL **92**, 074801 (2004)

Synchronization

Problem: Cannot synchronize bunches from linac to an external clock
(like a pump laser) to better than a few 100 fs

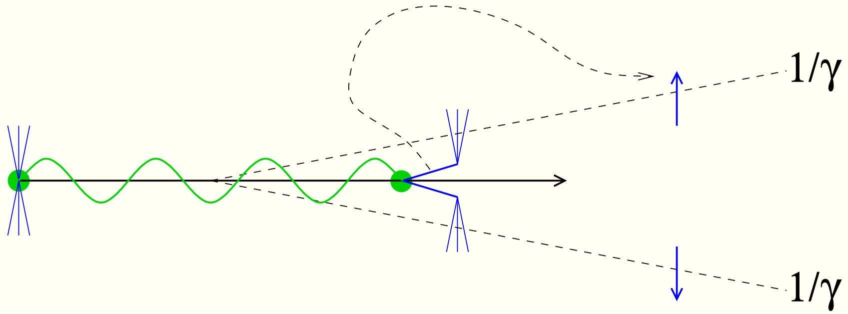
Solution 1: Cross-correlate electrons to laser light
demonstrated at SPPS with a precision of ca. 50 fs

Solution 2: Cross-correlate x-rays to laser light
hasn’t really been done yet

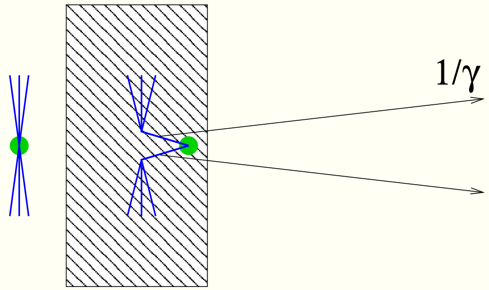
Solution 3: Derive x-rays and pump light from the same source
$\rightarrow$ synchronization, not only statistical correlation

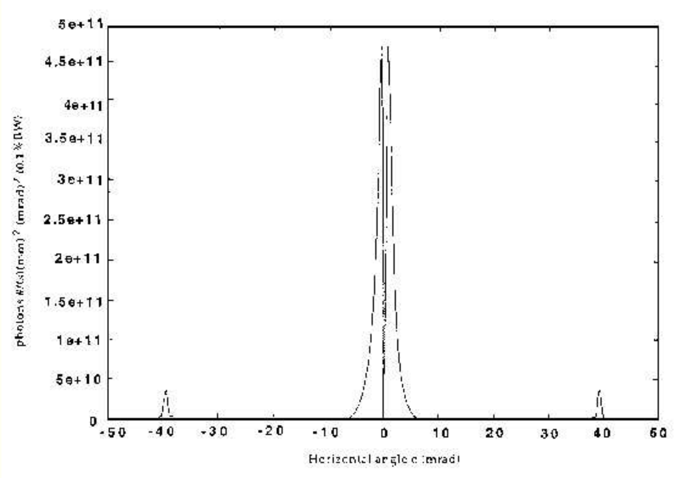
TUR

Transition **U**ndulator **R**adiation

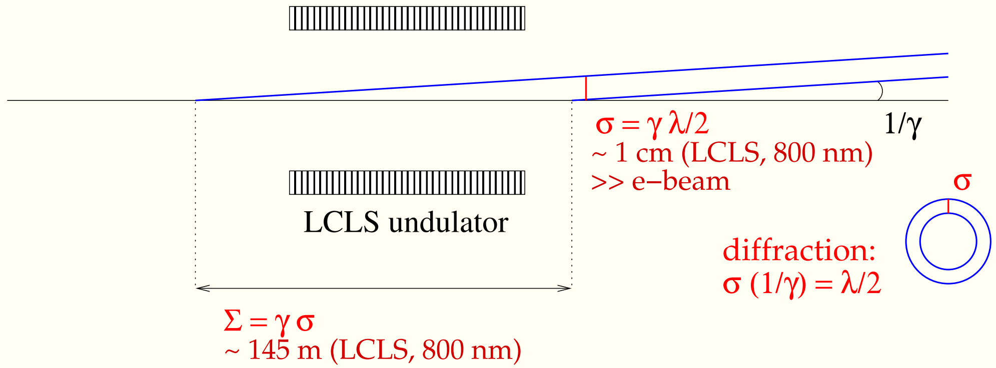


analogy to transition radiation:



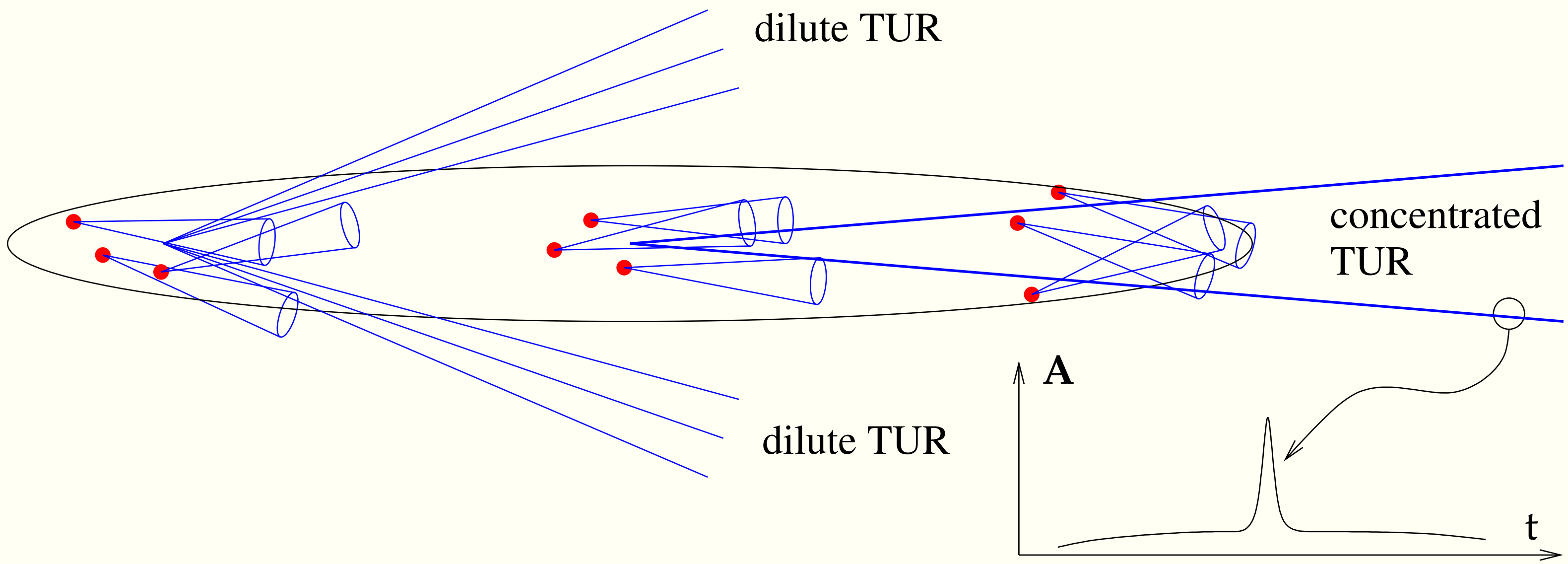


character of 1 transverse mode of TUR:



K.-J. Kim PRL **76**, 1244-1247 (1996)

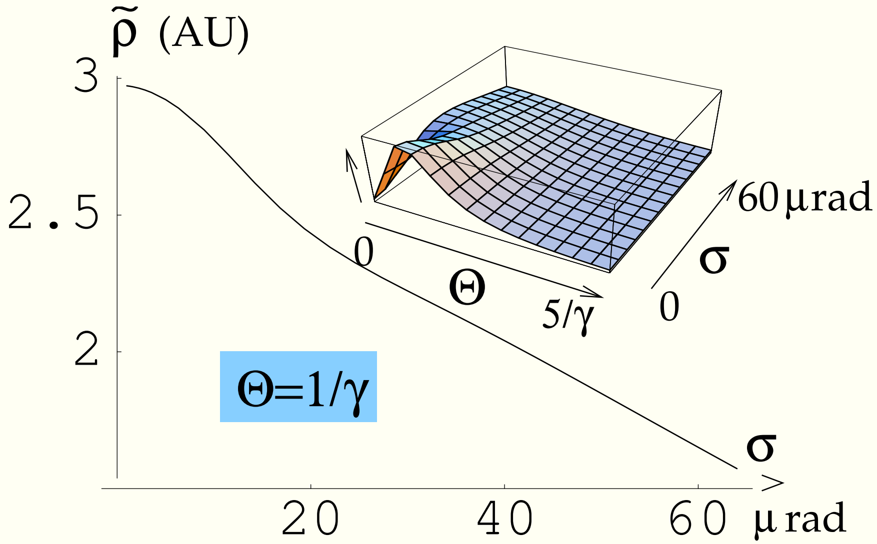
CTUR



Need beam divergence contrast of $> 1/\gamma$

BWA, Rev. Sci. Instrum, **76**, 063304 (2005)

Numbers



Directional electron density $\tilde{\rho}$

$$\tilde{\rho}(z, x', y') = \frac{\gamma^{-1}|\mathbf{\Theta} - \mathbf{x}'|}{(\mathbf{\Theta} - \mathbf{x}')^2 + \gamma^{-2}} \int d(\beta, x, y) \rho(X)$$

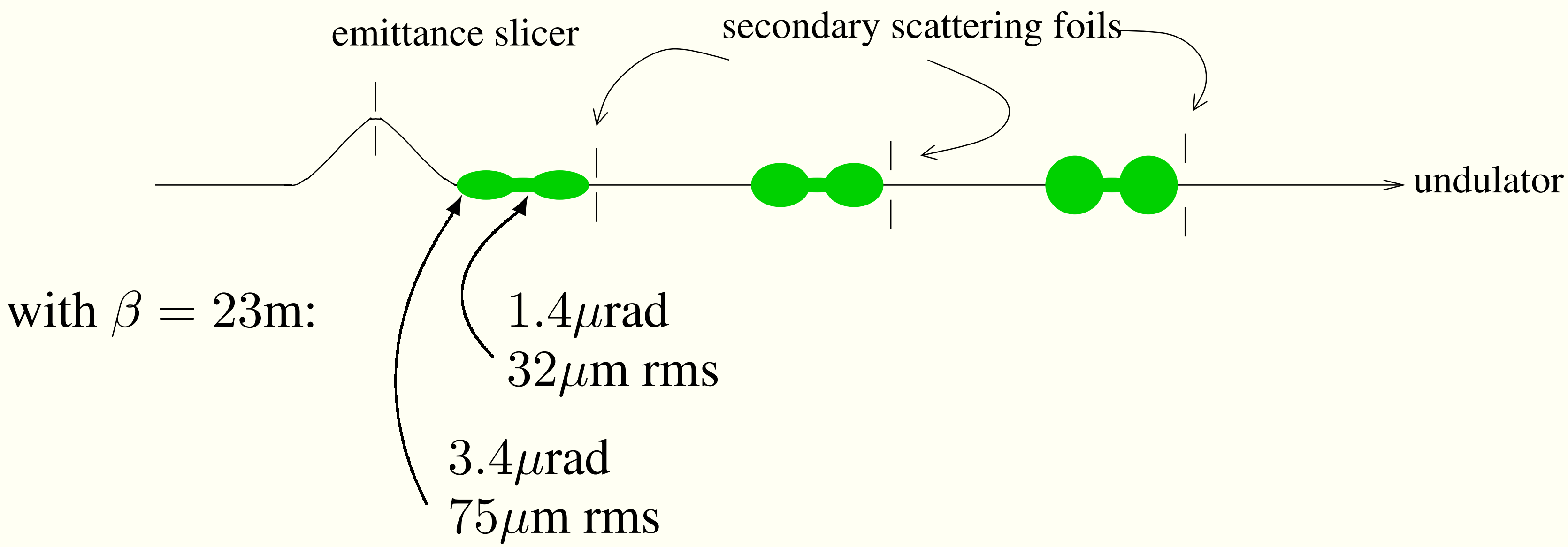
Θ is observation angle

For LCLS: need emittance increase of ca. 2000-fold for 50% CTUR contrast

Then, ca. 100 nJ IR light at 800 nm, 20 % bandwidth

Increasing the Emittance Contrast

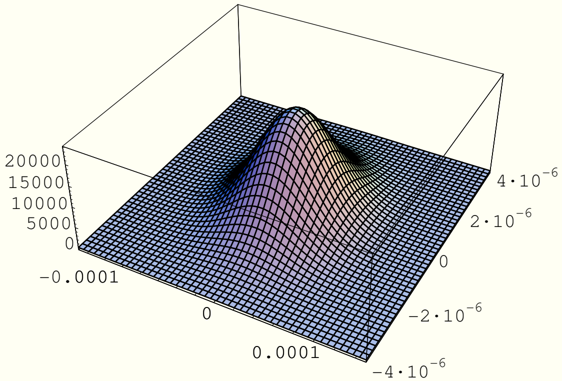
Emittance contrast is in both divergence and beam size:
secondary scattering foils make use of beam size contrast
to increase emittance contrast even further



space secondary foils at 1/2-β-function intervals to catch all electrons

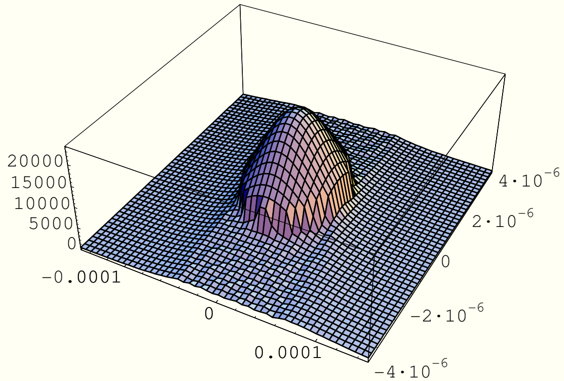
Simulations of the Emittance Contrast

center of bunch:

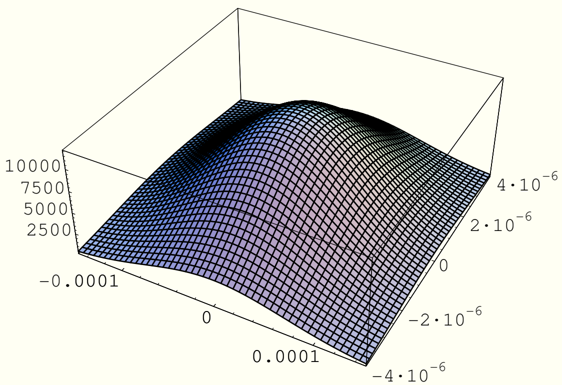


30 thin foils $\longrightarrow$

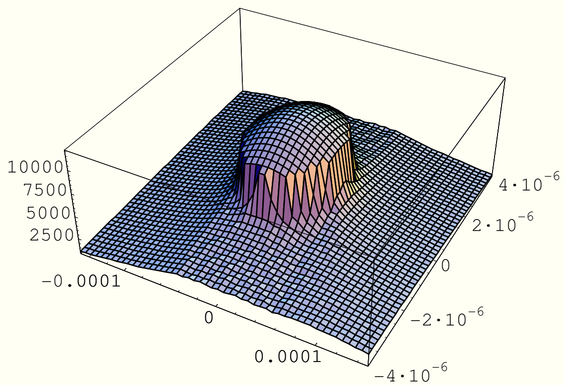
(same as primary)



emittance-sliced parts:



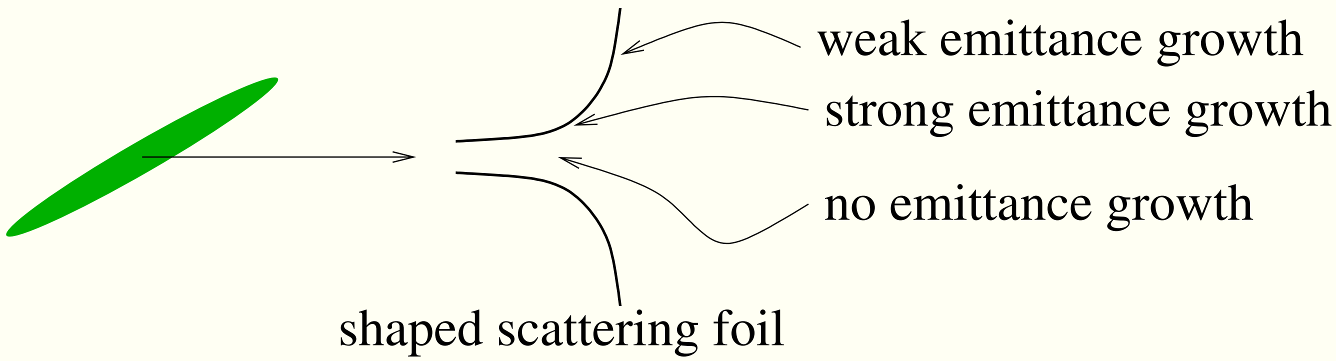
30 thin foils $\longrightarrow$



Problems

- With the beta function in the LCLS undulator given as 29m/rad, a 2500-fold emittance increase gives a beam 1.5 mm across
- Will lose lots of electrons, that's good for CTUR contrast, but bad for beam position monitors. Solution: Use shaped scattering foil
- CTUR arrives *after* x-rays, no good for pump-probe. Solution: use double-crystal monochromator to delay x-rays
- Clipping of CTUR light by beam pipe: modified transverse mode
- Need to investigate possible wakefield disturbance from additional scattering foils

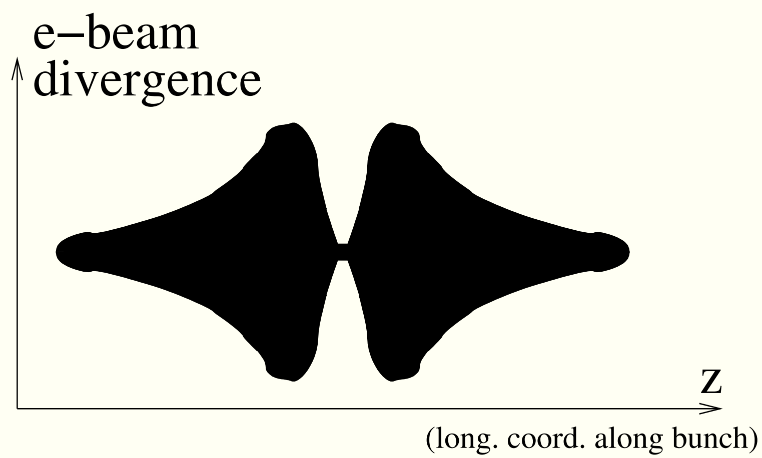
Shaped Scattering Foil



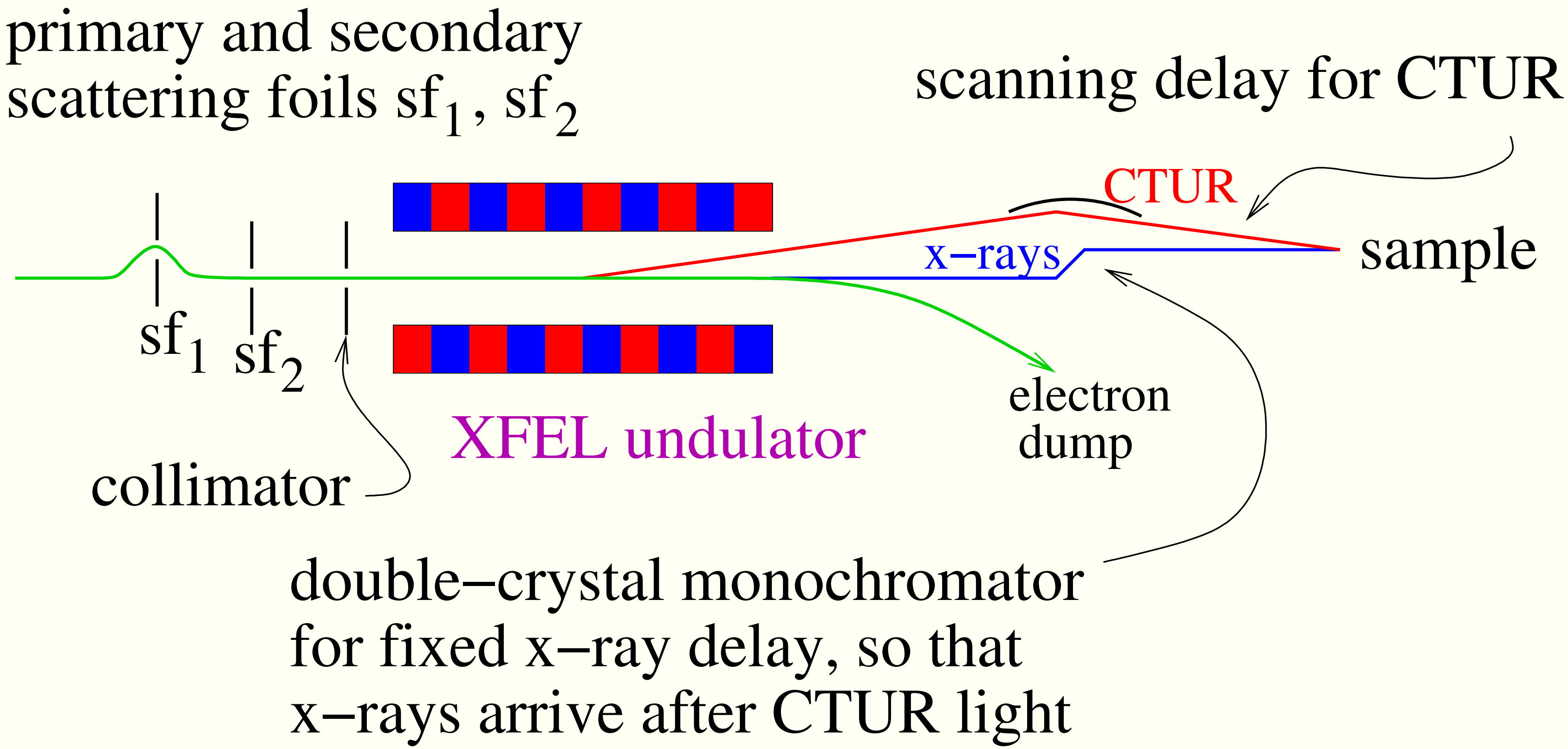
steep emittance slope near center

–> high–frequency Fourier components

–> short–wavelength CSR

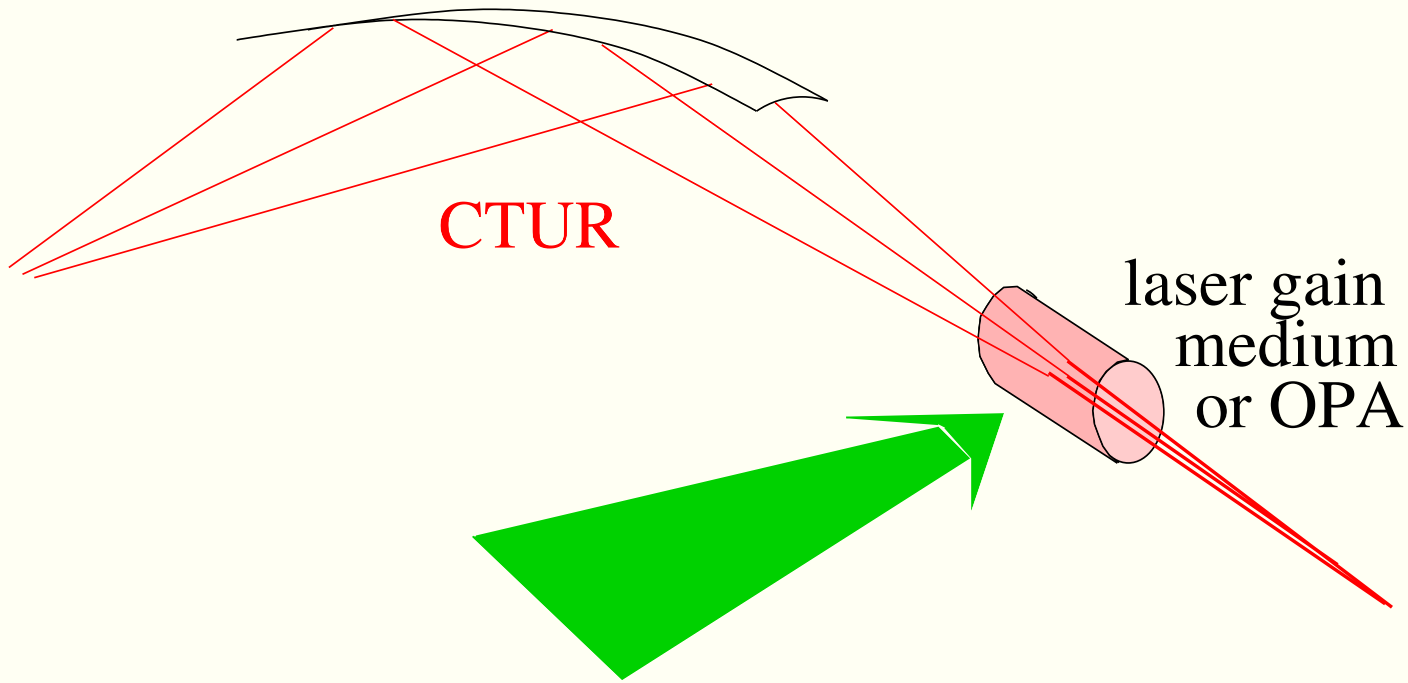


Overview


primary and secondary
scattering foils sf$_1$, sf$_2$
scanning delay for CTUR
CTUR
x−rays
sample
sf$_1$
sf$_2$
electron
dump
XFEL undulator
collimator
double−crystal monochromator
for fixed x−ray delay, so that
x−rays arrive after CTUR light

Boosting the IR power

send CTUR through one, or more, pre-pumped laser gain crystals,
or an Optical Parametric Amplifier in in-line configuration



Summary

- Scientific motivation for few-fs x-rays and synchronized light
- Synchronization is a problem
- How to use CTUR
- 100 nJ is enough to pump some experiments, but need to delay x-rays
- Otherwise, use CTUR for light-to-light cross-correlation (instead of electrons-to-light or x-rays-to-light)
- Use of shaped scattering foil
- Boost IR power with standard laser technology, if necessary