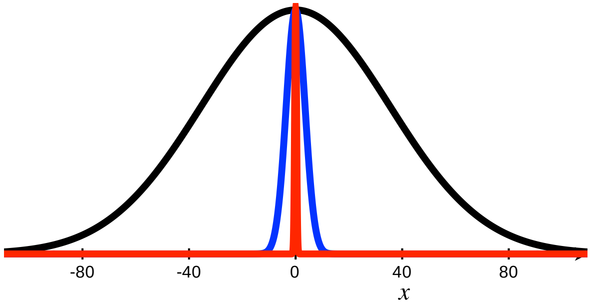
Science "inside" the synchrotron pulse width: X-ray pump/optical probe cross-correlation study of GaAs



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Proposal Title: Picosecond X-ray Detector for Synchrotrons (Award Number DE-SC0004078)

Areas of Progress:

1. Coplanar stripline ultrafast x-ray detector
2. X-ray pump/optical probe synchrotron study
3. LCLS pulse length study (preliminary)

Challenge: x-ray synchrotron measurements much faster than the pulse width

If a material is pumped by a 100 fs laser, how do you measure its response to x-rays with picosecond precision when the synchrotron x-ray pulses have ~100 ps FWHM?

Best approach to date: laser "slicing" of the electron bunch

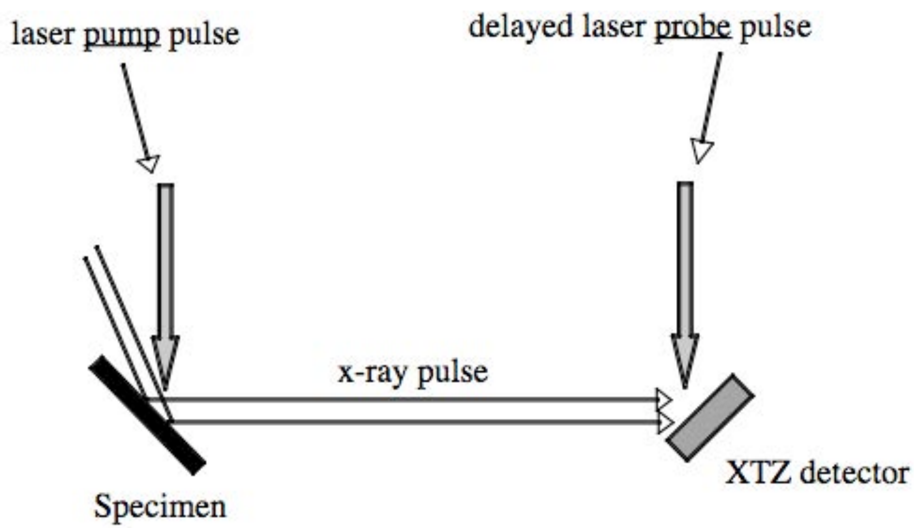
E.g. ALS study of VO_2 dynamics (Cavalleri *et al.* PRL 2005)
SLS study of Bi phonons (Beaud *et al.* PRL 2007)

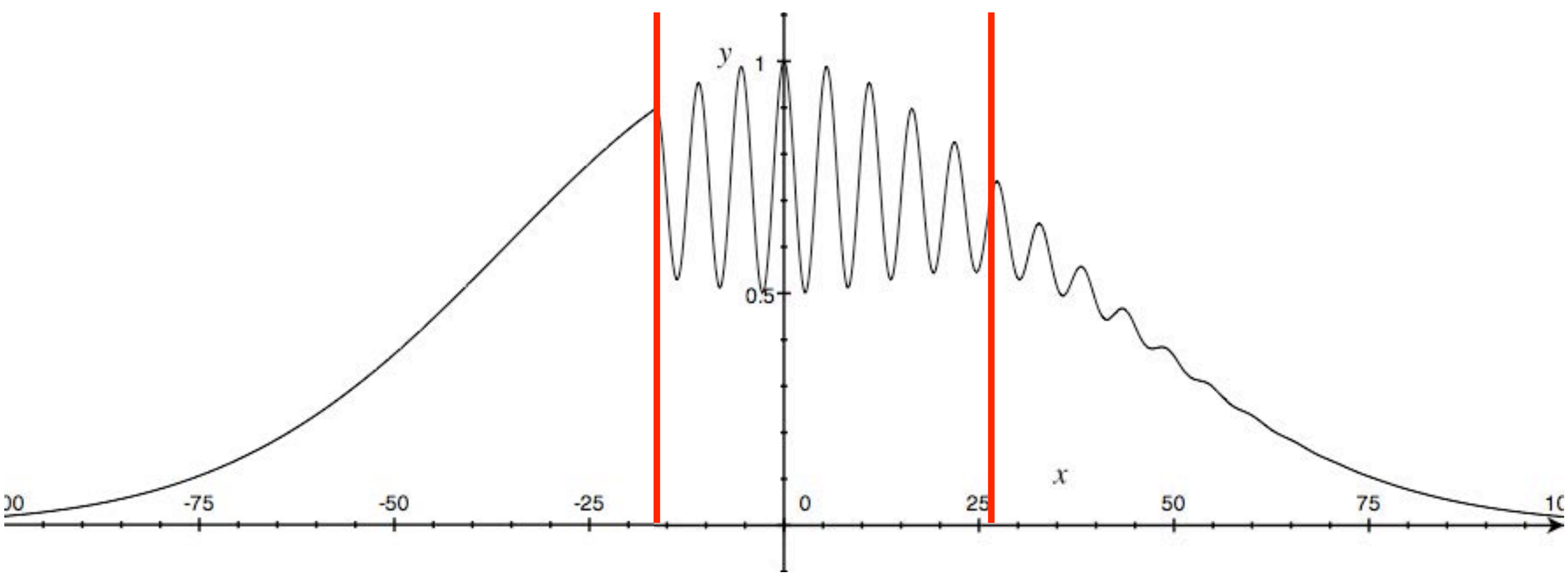
Drawbacks:
1. Requires perturbation of the stored particle beam
2. Commensurate loss of intensity

Proposed solution to first drawback: "slice" the detector, not the particle beam.

(Solution to second drawback requires shorter bunches.)

1. Coplanar stripline ultrafast x-ray detector





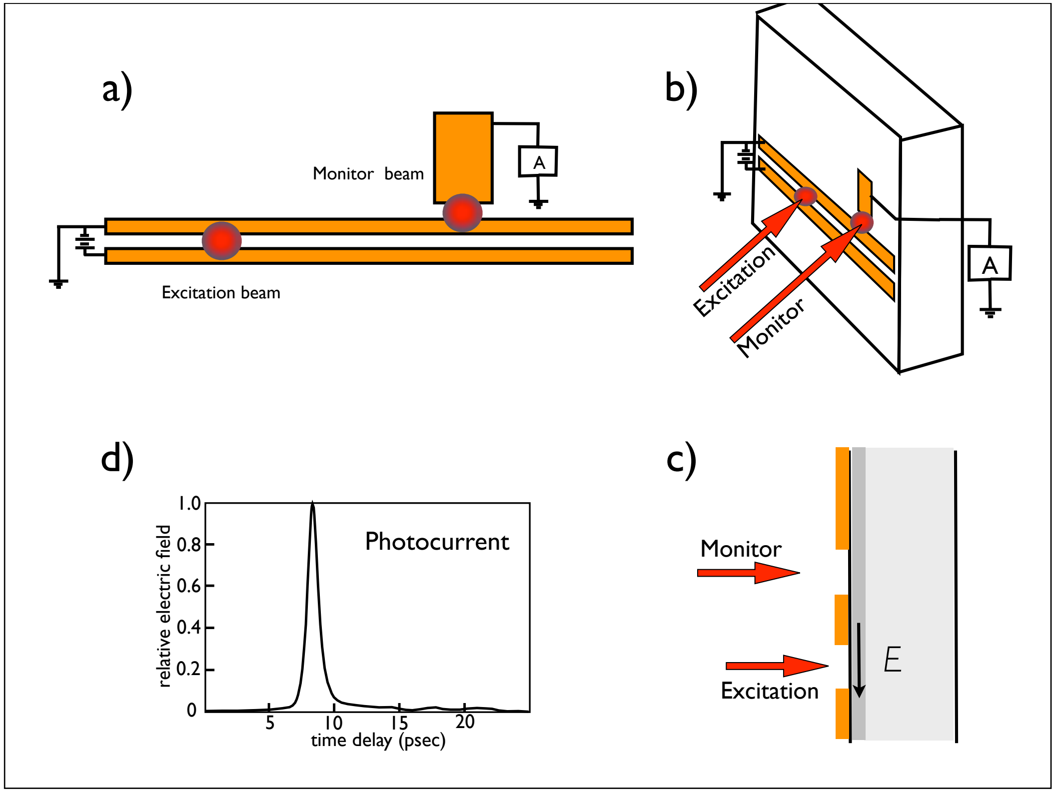
1. Coplanar stripline ultrafast x-ray detector

Concept was developed for measuring laser pulse profiles for THz emitters (Fattinger & Grischkowsky APL 1988). For the x-ray detector, replace the 100 fs laser excitation pulse with the 100 ps x-ray synchrotron pulse.

Current pulse created in the stripline is "sliced" by the monitor laser pulse.

Substrate is a high resistance semiconductor, implanted to reduce carrier recombination lifetimes.

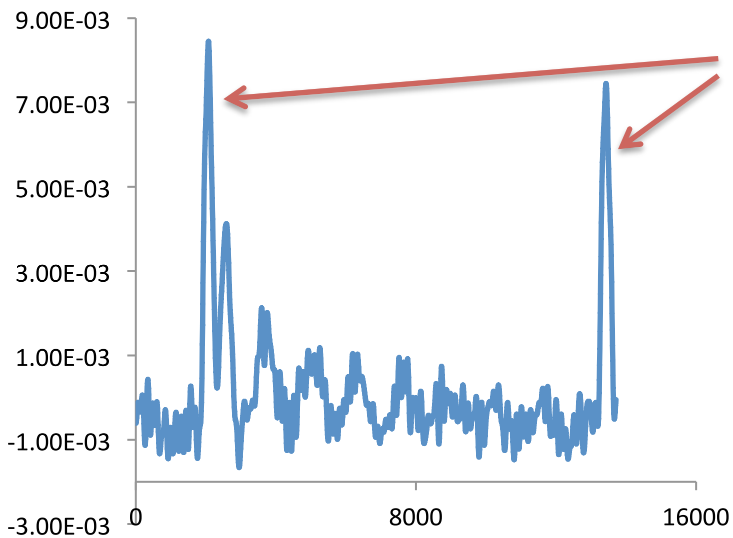
Monitor current is measured as a function of pump-probe time delay.



1. Coplanar stripline ultrafast x-ray detector

RESULTS:

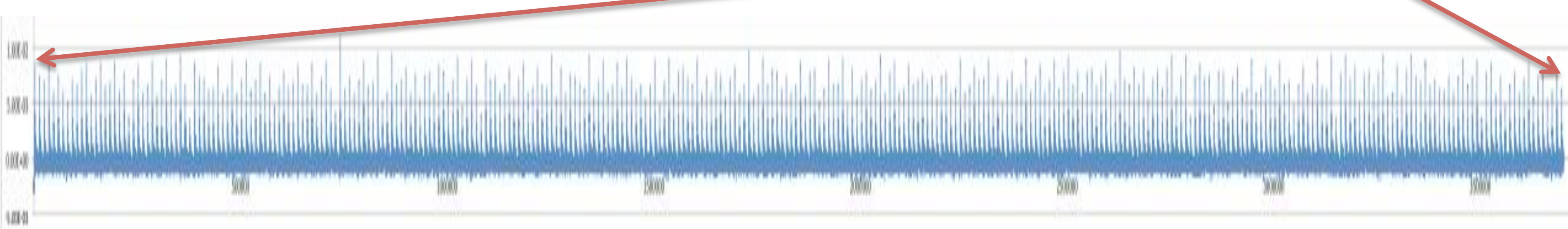
1. Prototypes tested for Si and then GaAs (better)
2. Large signals present in striplines for focused APS hard x-ray beams
3. Stripline output gives real-time bunch profiles, at time resolution limited by the speed of the digital oscilloscope:



Consecutive x-ray pulses in 324-bunch mode, 11.3 ns apart

N.b. these are without “slicing”

All 324-bunches, single pass:



1. Coplanar stripline ultrafast x-ray detector

Next step: implement slicing

Initial laser monitor probe tests show strong signals. Need modulation (chopper) and lock-in detection. Next beam time at APS sector 7….

Issues:

1. Match impedances to minimize ringing (not critical)
2. To reduce carrier recombination lifetime to sub-picoseconds, we implanted with 8 MeV protons (Purdue PRIME Lab). For silicon this was OK, but for GaAs this leads to activation of ^{74}As, a gamma emitter (17 day half-life). Need to avoid this!

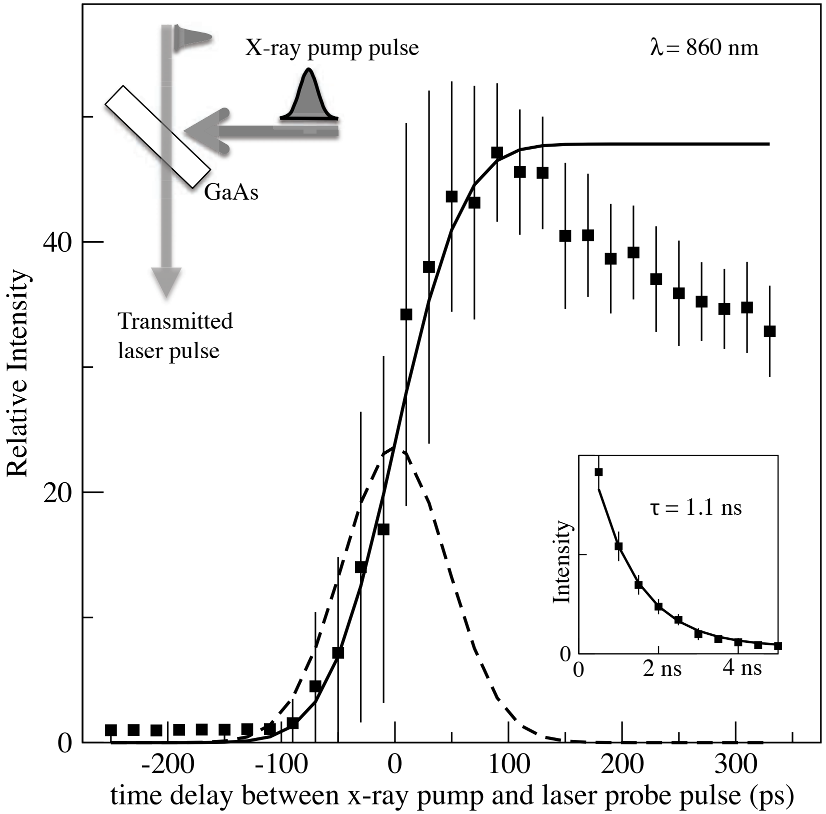
2. X-ray pump/optical probe synchrotron study

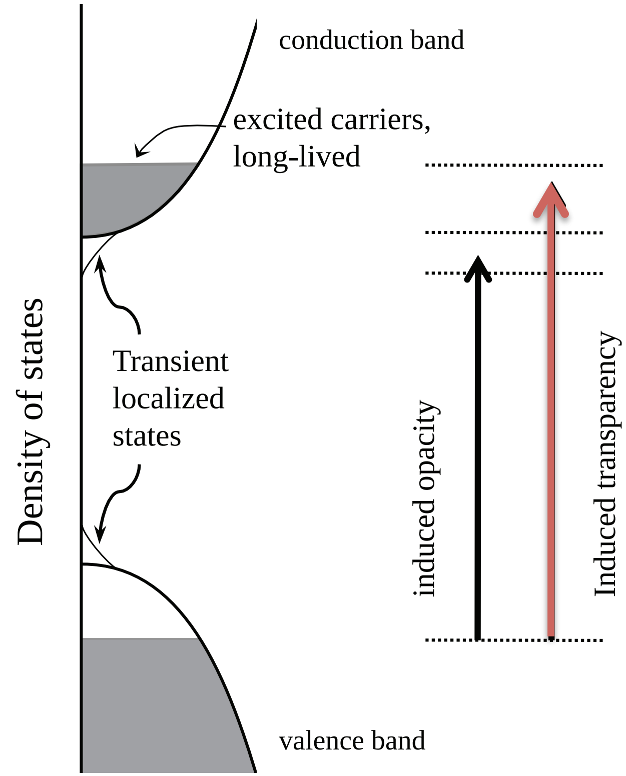
To help understand the response of GaAs, we have conducted a cross-correlation study of GaAs that does measure “inside” the synchrotron pulse width.

Using extremely intense synchrotron pulses (APS ID-14-D two undulators, no monochromator, focused to 100 microns), this semiconductor exhibits

- X-ray induced optical transparency (lifetime ~ ns)
- X-ray induced optical opacity (lifetime ???)

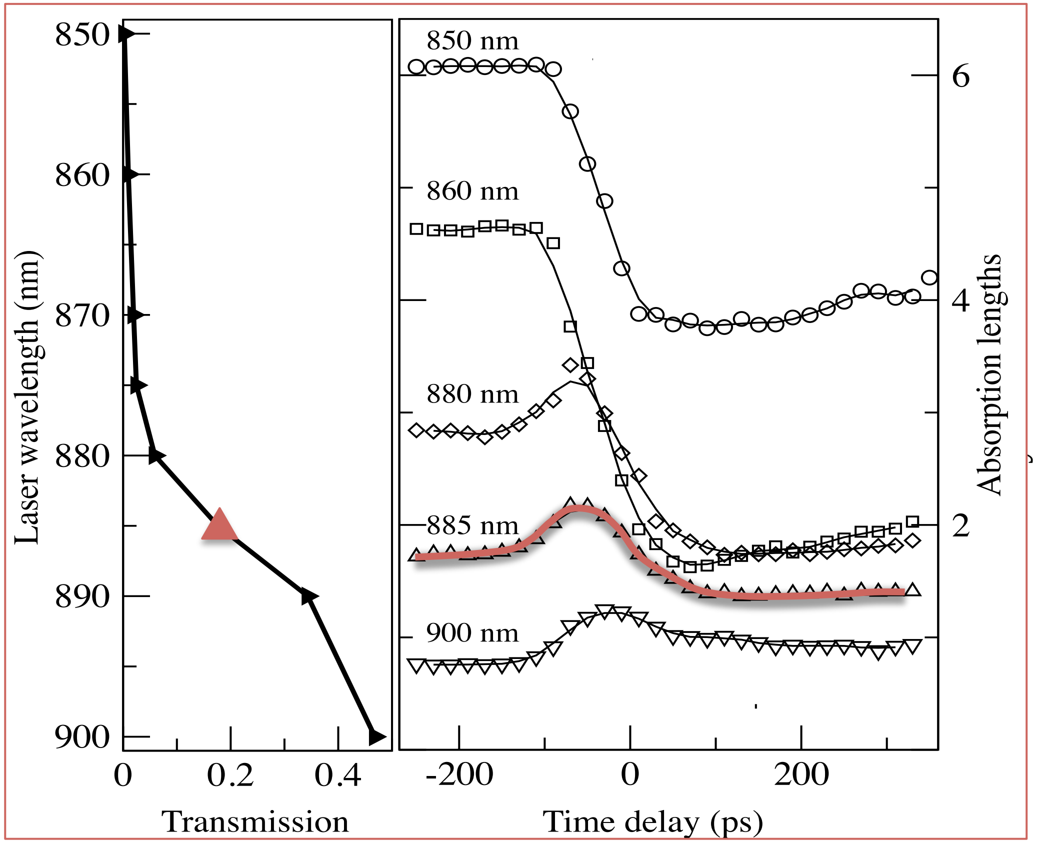
2. X-ray pump/optical probe synchrotron study

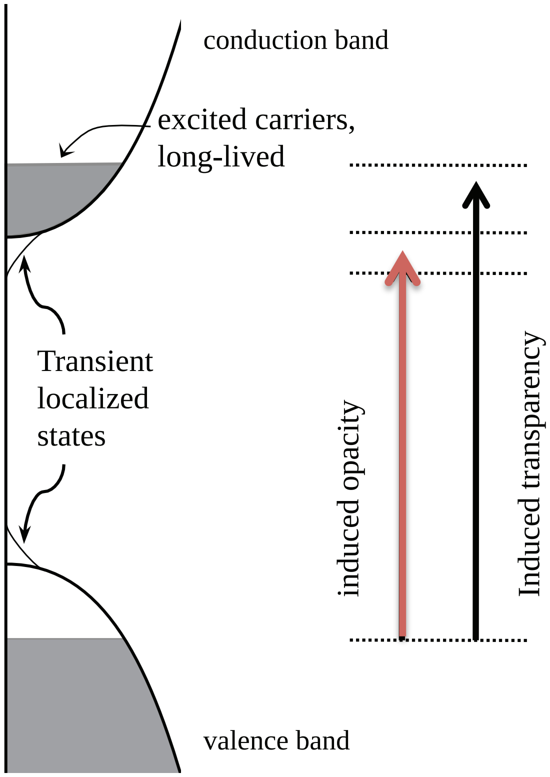




X-ray induced optical transparency

2. X-ray pump/optical probe synchrotron study





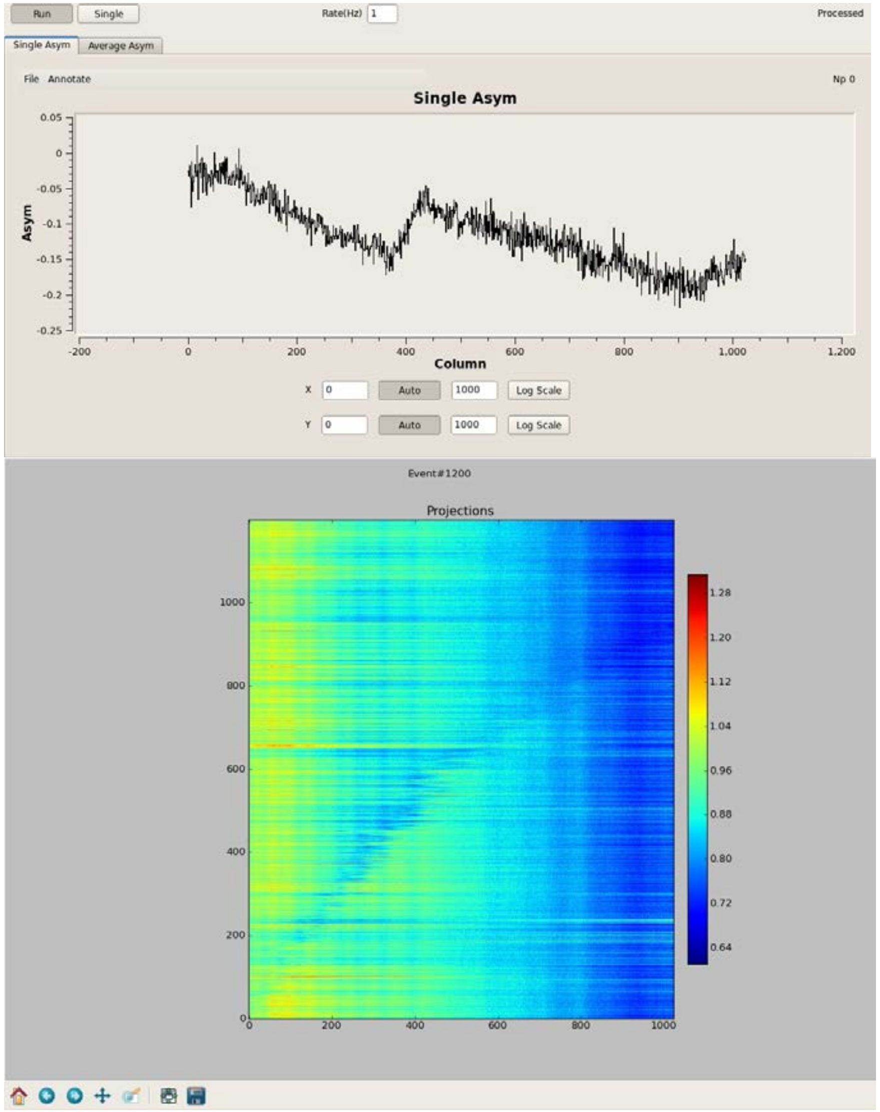
X-ray induced optical opacity

3. LCLS pulse length study (preliminary)

A few days ago (Aug 14) I joined Ryan Coffee *et al.* for 12 hours of LCLS beam time. Optical absorption through thin SiN membranes was recorded as ~10 fs LCLS pulses at 800 eV struck the specimens.

Clear responses were seen in the raw data, which may lead to improved techniques for measuring the arrival time and pulse width of these ultra-short pulses.

It will be of great interest to repeat the GaAs cross-correlation study with LCLS hard x-rays to observe the sub-picosecond response of induced opacity.



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Questions?