Laser-induced CSR: toward a probe to explore wakefields in storage rings?

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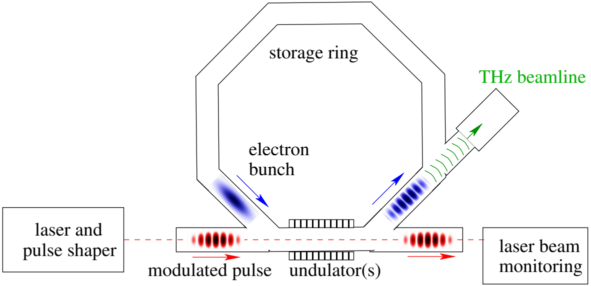
Manipulation of electron bunches using an external laser

UVSOR II, normal alpha mode

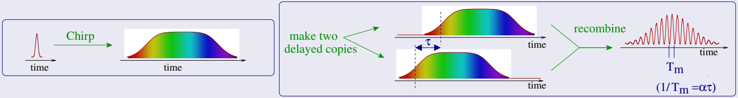


- Energy 600 MeV, bunch length ≈ 3 cm, rel. energy spread $\approx 3.4 \times 10^{-4}$.
- Detection just after straight tranport of few turns
- Normal alpha mode, current well below the microbunching instability threshold.

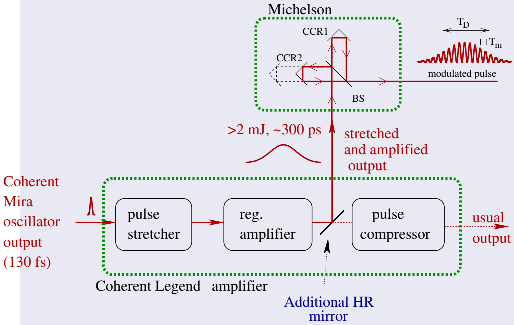
Sine modulation of the laser pulses: experimental details

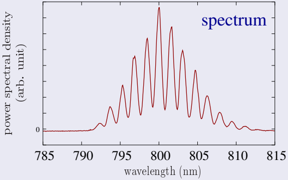
Principle: *chirped pulse beating*

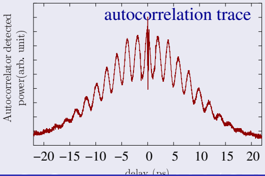
[Weling and Auston JOSA B 13, 2783 (1996)]



Actual experimental setup

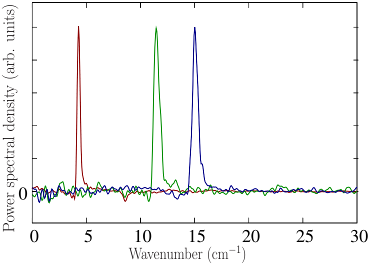




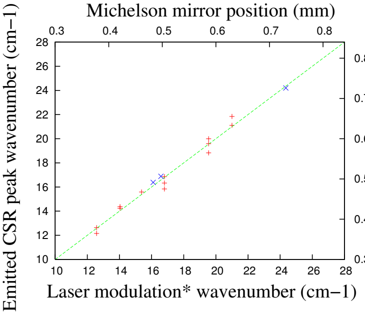


Typical spectra, tunability (UVSOR-II storage ring)

- Typical spectra



- Tunability



Experiments at UVSOR: Evain et al., PRSTAB, 090703 (2010), SB et al. Nature Phys. 4, 390 (2008).

Previous conjectures: Byrd et al. PRL 96, 164801 (2006), Y. Takashima et al., UVSOR Activity Report 30, 56, (2003).

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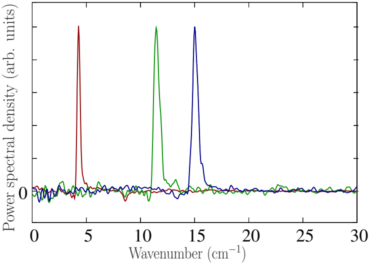

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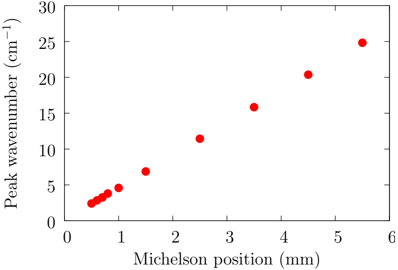

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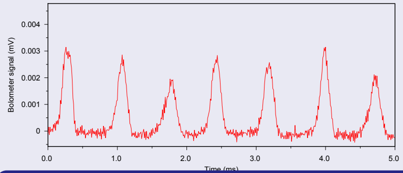
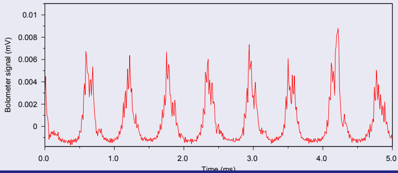
What happens at higher current?

- Interaction between electrons via wakefields

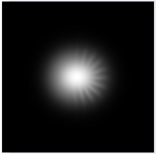
  $\Longrightarrow$ Without laser: microbunching instability.

Typical experimental signals (UVSOR, low-alpha)

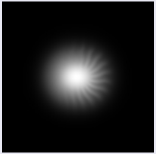




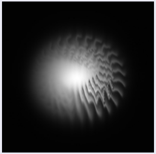
Numerical simulations (Vlasov FP+parallel plate wakefield)



$I = 5$ mA



$I = 6$ mA



$I = 12$ mA

Exp. studies at, eg, ALS, BESSY, ANKA, MLS, SOLEIL, DIAMOND... Also in compact rings such as CIRCE, SURF, NSLS...

Modeling and num. studies. see eg: Venturini et al., PRSTAB 8, 014202 (2005), Stupakov and Heifets, PRSTAB 5 054402 (2002), Th./exp. detailed comparisons: Evain et al. EPL, to appear.

New information from the response to a laser perturbation?

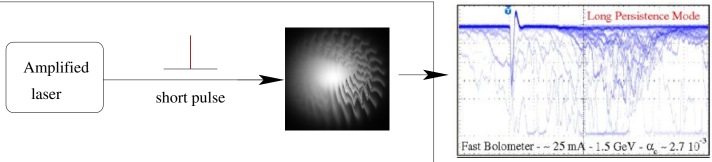
PRL 97, 074802 (2006) PHYSICAL REVIEW LETTERS week ending 18 AUGUST 2006

Laser Seeding of the Storage-Ring Microbunching Instability for High-Power Coherent Terahertz Radiation

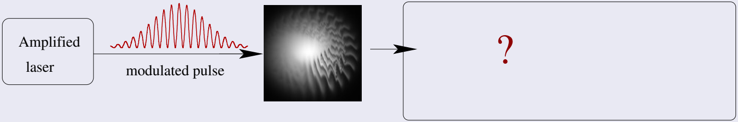
J. M. Byrd, Z. Hao, M. C. Martin, D. S. Robin, F. Sannibale,* R. W. Schoenlein, A. A. Zholents, and M. S. Zolotorev

Ernest Orlando Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, California 94720, USA

(Received 24 May 2006; published 18 August 2006)



What would happen if we use a sine perturbation?



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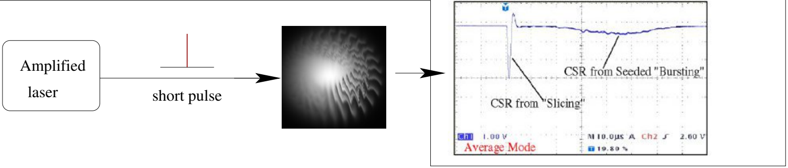

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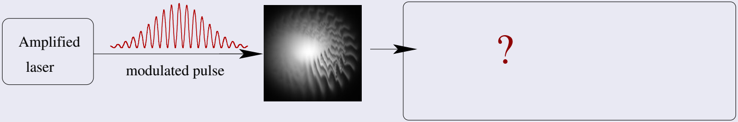
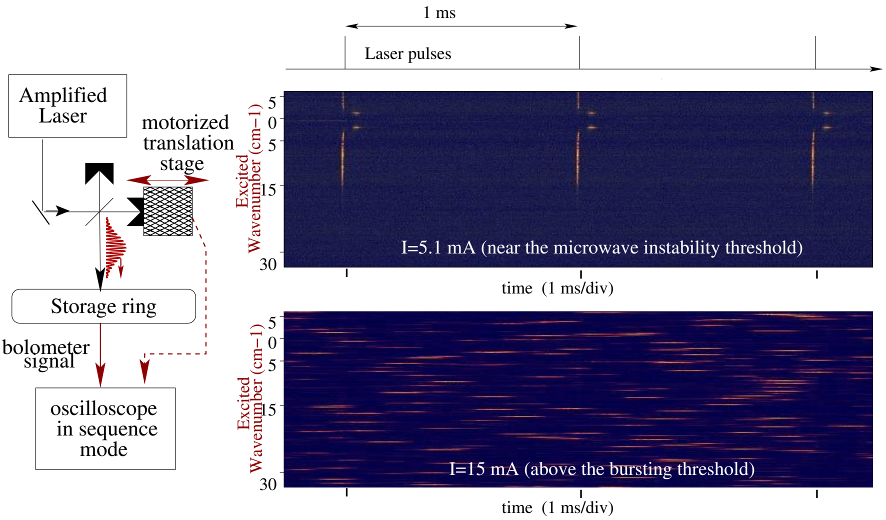
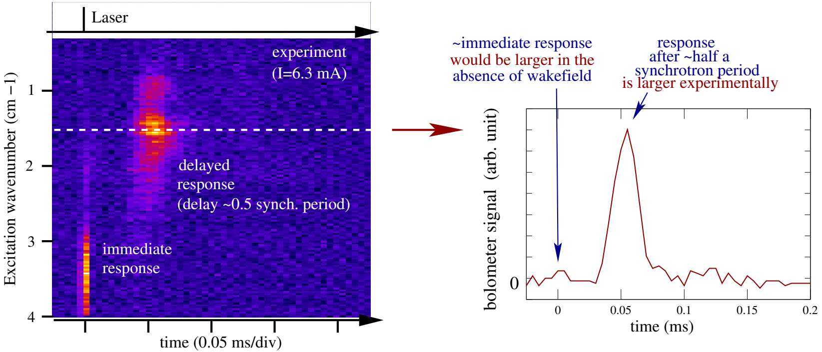
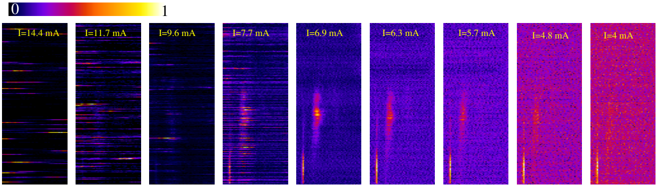


Bolometer response versus modulation wavenumber: global view

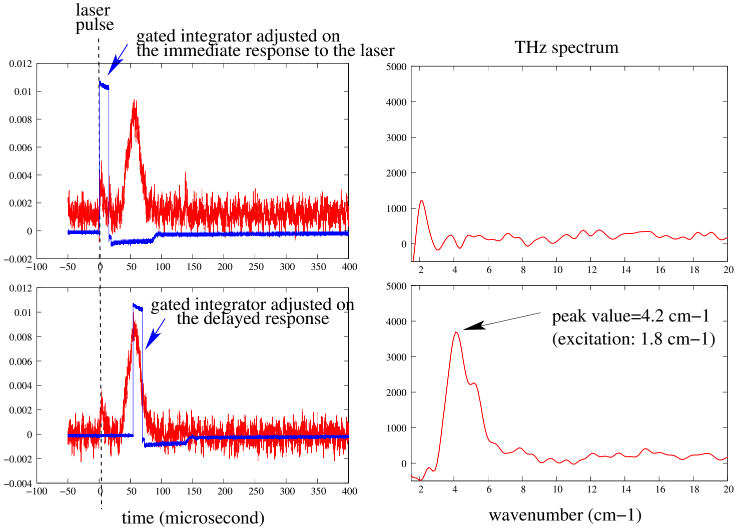


Bolometer response versus modulation wavenumber: Zoom on the relevant wavenumber range





Spectrum of the delayed response?



- Detected wavenumber is ≈ 2 times larger than initial modulation.

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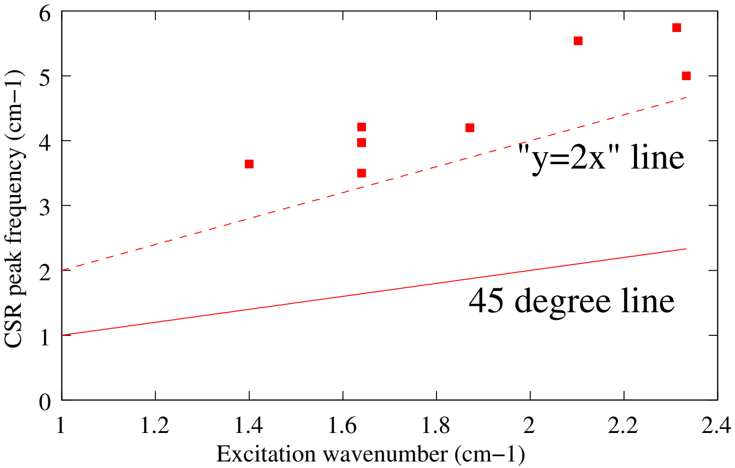


- Detected wavenumber is ≈ 2 times larger than initial modulation.
- Question: do we simply detect the second harmonic of the modulation?

Modeling

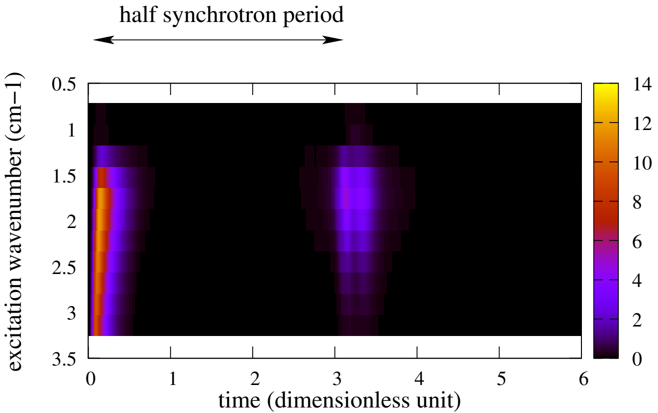
- Vlasov-Fokker-Planck equation (1d) for the normalized electron density $f(q,p,\theta)$. q =space, $p =$ momentum, θ =time (dimensionless).

$$\underbrace{\frac{\partial f}{\partial \theta} - p\frac{\partial f}{\partial q} + q\frac{\partial f}{\partial p}}_{\text{rotation at synch. freq.}} \quad \underbrace{-I_c E_{WF}\tfrac{\partial f}{\partial p}}_{\text{wakefield}} \quad \underbrace{= 2\epsilon\frac{\partial}{\partial p}\left(pf + \frac{\partial f}{\partial p}\right)}_{\text{diffusion and damping}}$$

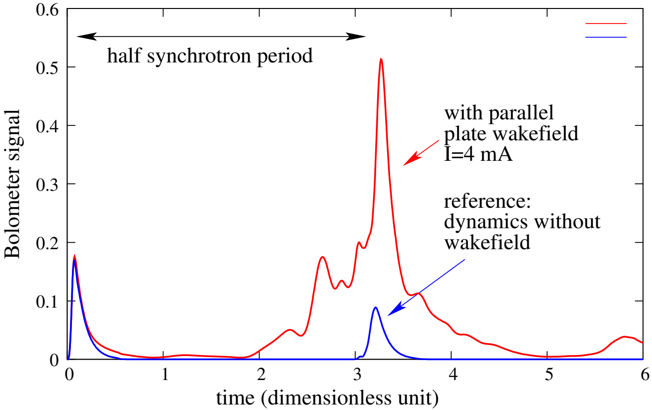
- Wakefield=constant curvature + parallel plates [Murphy *et al.* Particle Accel., 57, 9 (1997)]
- Units of q and p: RMS size at equilibrium, when $I_c = 0$.
- Unit of time (θ): one synchrotron period corresponds to 2π.

Preliminary numerical results

- Bolometer response versus excitation wavenumber



Typical simulated bolometer signal (excitation wavenumber=1.4 cm^{-1})

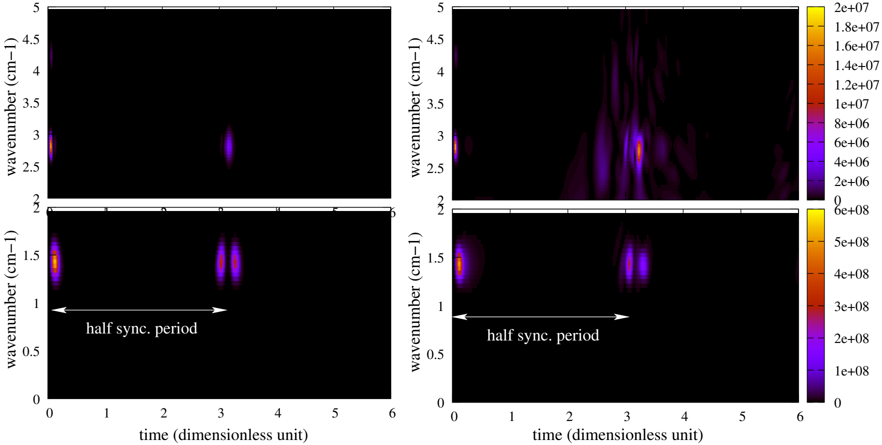


- Beamline cutoff: 2 cm^{-1}
- Bolometer time response: 2 μs

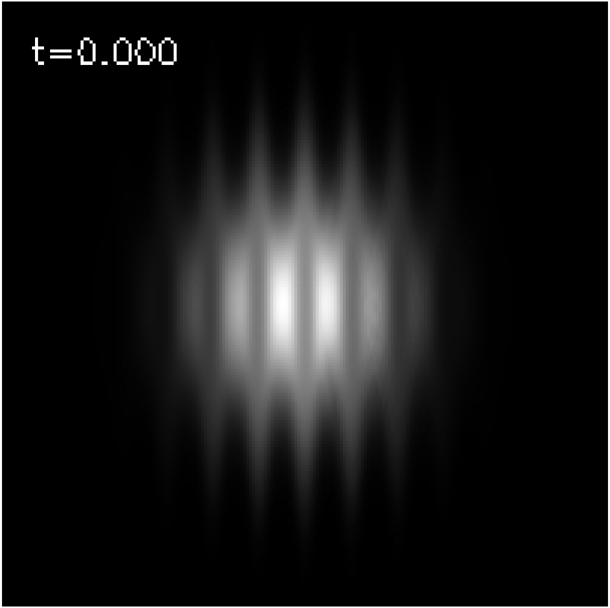
Numerical results: form factor versus time

Reference without wakefield $I = 0$

With wakefield $I = 4$ mA



Phase space evolution



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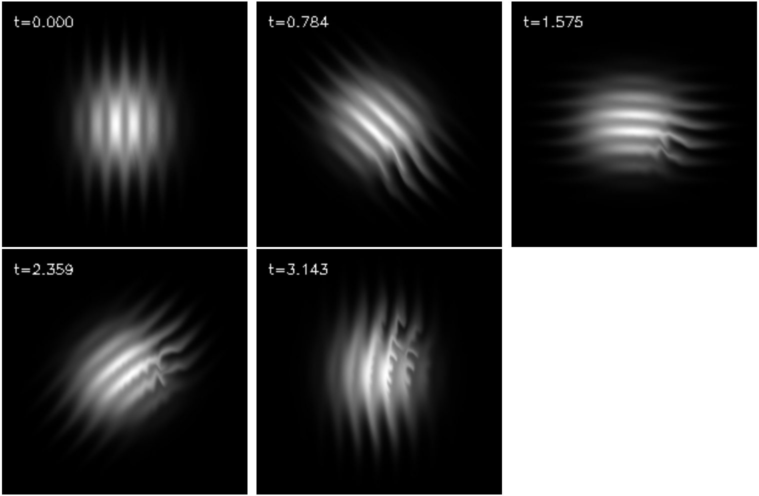
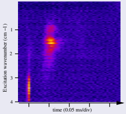


Conclusion

New experimental capabilities

- Modulated laser pulses can also trigger the MB instability.
- This map provides a new fingerprint of the dynamics, in which wakefields are essential.



Comparison with theory

- Simplest models (1d Vlasov FP+parallel plate wakefields) present agreements, eg, the response at ≈ twice excitation frequency.
- Differences in the "fingerprints" are also present.

Some future directions

- Improve models, in particular included wakefield models (and couple to Vlasov-FP), so that signatures match as much as possible. Ideas: [Agoh and Yokoya PRSTAB 7, 054403 (2004)/Stupakov and Kotelnikov PRSTAB 12, 104401 (2009)].
- Compare outputs from different integration methods.
  $\rightarrow$ Vlasov Fokker-Planck versus maroparticle codes: see poster WEPPR045.