Laser-induced CSR : seeding of the microbunching instability in storage rings ?

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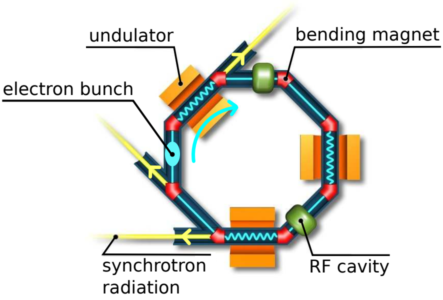
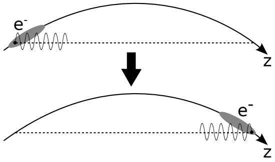
Outline

1. Storage-ring microbunching instability
2. Seeding setup (at mm wavelength using an external laser)
3. Results of seeding at UVSOR-II

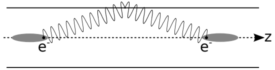
Microbunching instability in storage rings



- Free space wakefield

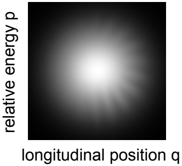


- Parallel plates wakefield



- If charge density > density threshold, interaction between the electron bunch and its radiation (wakefield) ⇒ microbunching instability

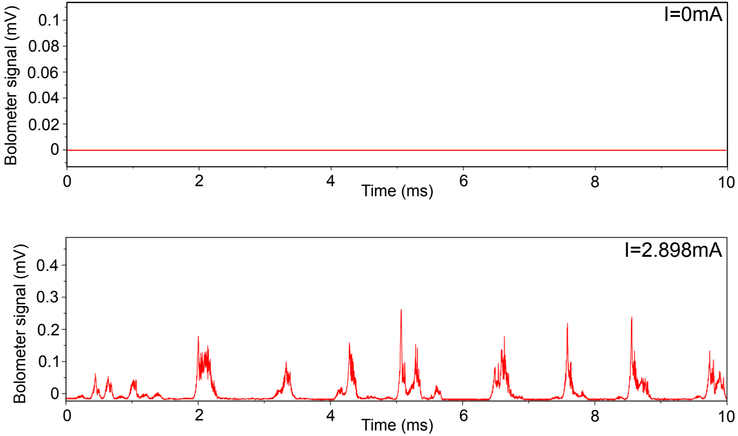
- Appearance of microstructures (at millimeter scale)



Microbunching instability in storage rings

Experimental observation : emission of CSR at THz frequencies

(bolometer signals : UVSOR-II, low-alpha & single bunch mode)



Modeling

Vlasov-Fokker-Planck (1D) equation

$$\frac{\partial f}{\partial \theta} = p\frac{\partial f}{\partial q} - q\frac{\partial f}{\partial p} \quad \Rightarrow \quad \text{rotation in phase space O(kHz)}$$

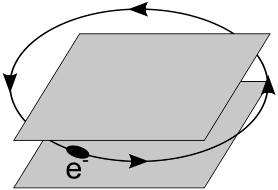
$$+ 2\varepsilon\frac{\partial}{\partial p}\left(pf + \frac{\partial f}{\partial p}\right) \quad \Rightarrow \quad \text{damping + diffusion O(ms)}$$

$$+I_c E_{wf}\frac{\partial f}{\partial p} \quad \Rightarrow \quad \text{wakefield}$$

[Venturini and Warnock, Phys. Rev. Lett. 89, 224802 (2002)]

- $f(q, p, \theta)$: normalized electron distribution
- q : longitudinal position (in units of r.m.s. bunch length at equilibrium)
- p : relative energy (in units of relative energy spread at equilibrium)
- θ : time (dimensionless, 2π = one synchrotron period)

- $E_{wf}(q)$: electron moving on a circular orbit in the midplane between two parallel plates of infinite conductivity. [Murphy et al, Part. Acc. (1997)]



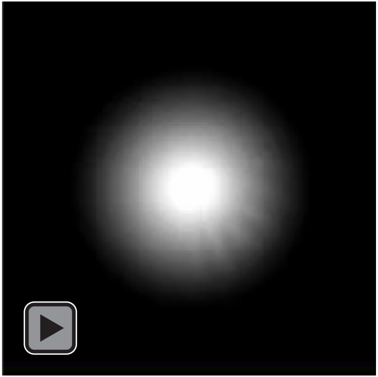
Phase space versus time (numerical)

Numerical result : evolution of the electron distribution

(Vlasov-Fokker-Planck model + shielded CSR wakefield, UVSOR-II, low-alpha mode)

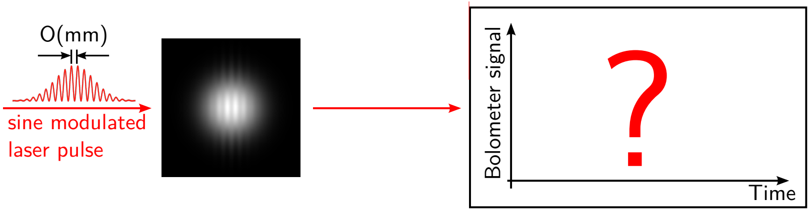
- Below microbunching instability threshold, I = 3mA

- Around microbunching instability threshold, I = 5mA



⇒ The structure has a characteristic wavenumber

Principle of seeding : initial bunching using an external laser



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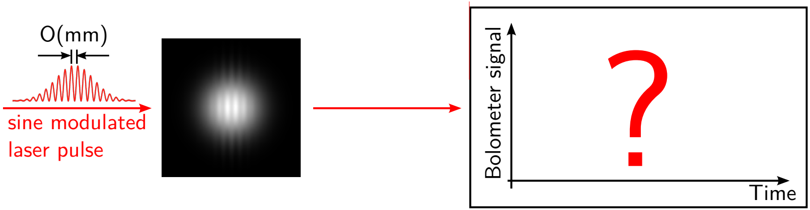
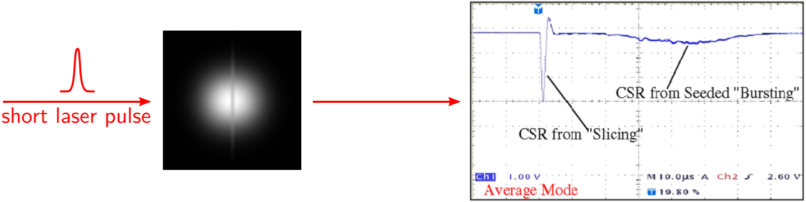


Motivation : previous results in conditions of slicing

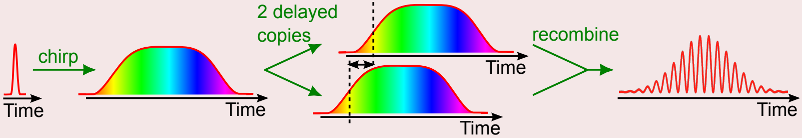
[Byrd et al, Phys. Rev. Lett. 97, 074802 (2006)]
"Laser Seeding of the Storage-Ring Microbunching Instability for High-Power Coherent Terahertz Radiation"



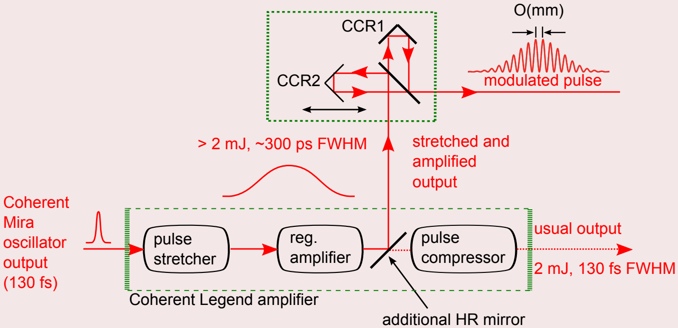
Setup for the production of modulated laser pulses

Chirped pulse beating

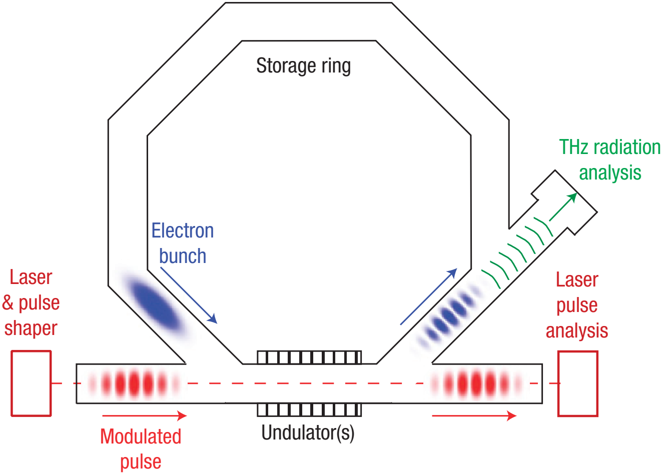
[Weling and Auston, JOSA B 13, 2783 (1996)]



Experimental setup



Global view of the experimental setup

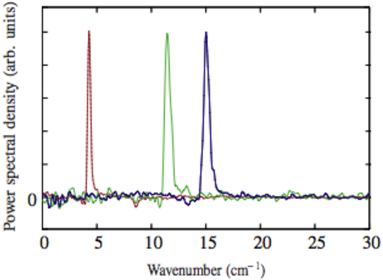


- UVSOR-II, normal alpha and single bunch mode.
- Energy 600 Mev, relative energy spread $\approx 3.4 \times 10^{-4}$ and rms bunch lenght ≈ 3 cm.
- Beam current below the microbunching instability threshold.

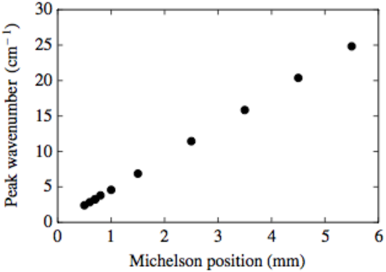
Tests without microbunching instability : effective bunching at mm scale

Experiments at UVSOR :

- [Evain et al, Phys. Rev. STAB 13, 090703 (2010)]
- [Bielawski et al, Nature Phys. 4, 390 (2008)]



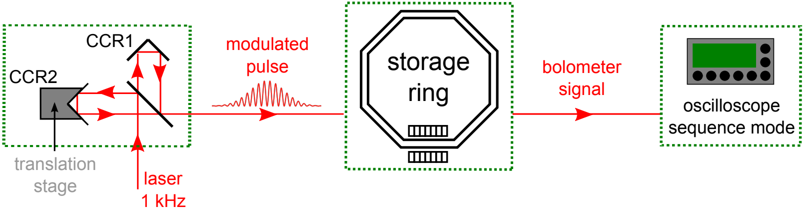
Typical emission spectra induced by the shaped laser pulses.

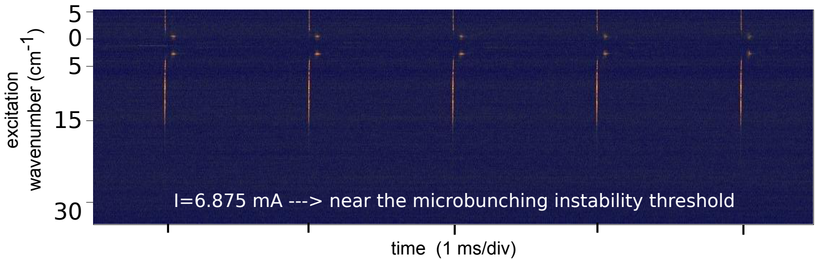


Tunability of the peak terahertz emission frequency.

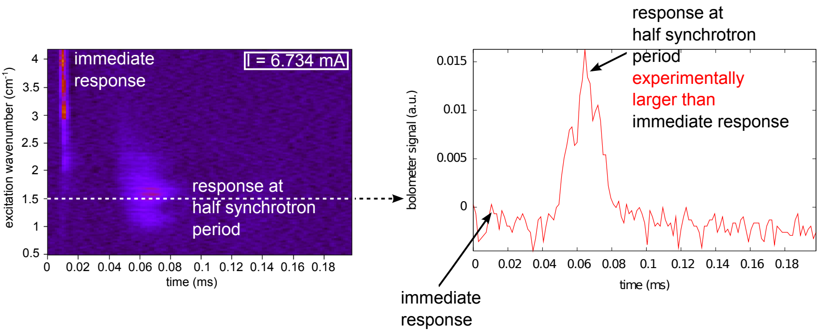
$\Rightarrow$ Observation of narrowband THz emission in a bending magnet

Seeding results below and above microbunching instability

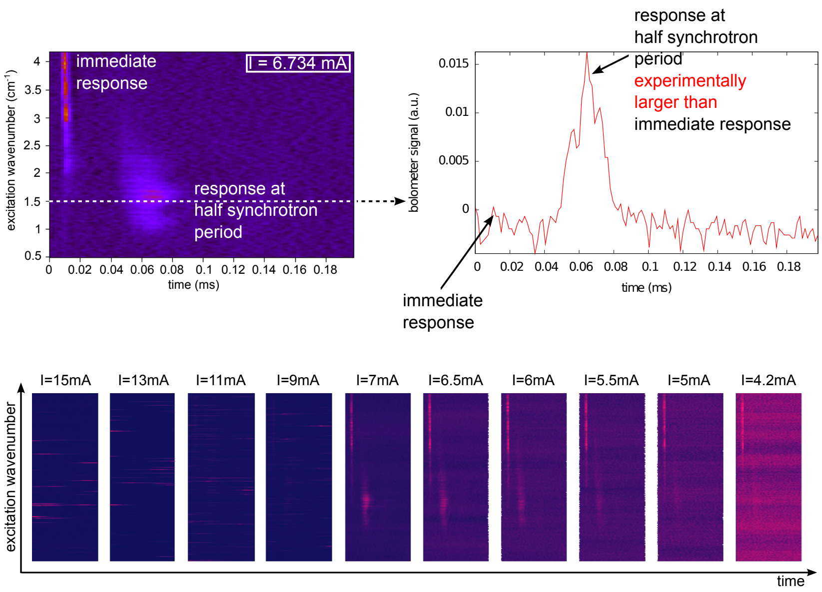




Zoom of bolometer signal versus excitation wavenumber

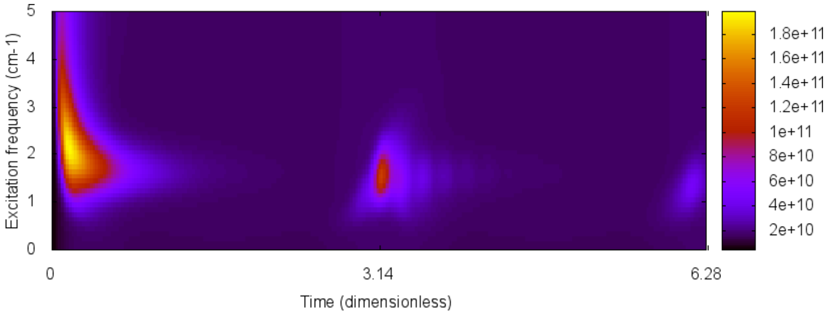


Zoom of bolometer signal versus excitation wavenumber



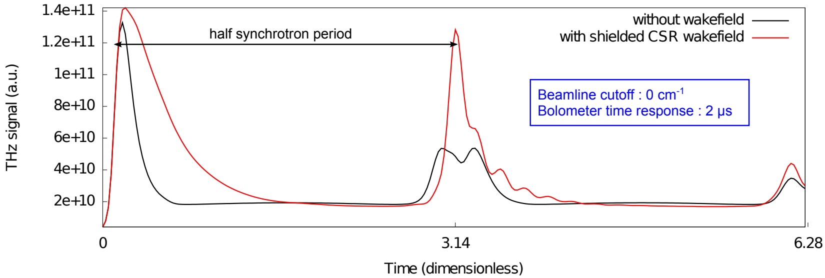
Numerical result : CSR versus time

For a beam current I = 3.5 mA :

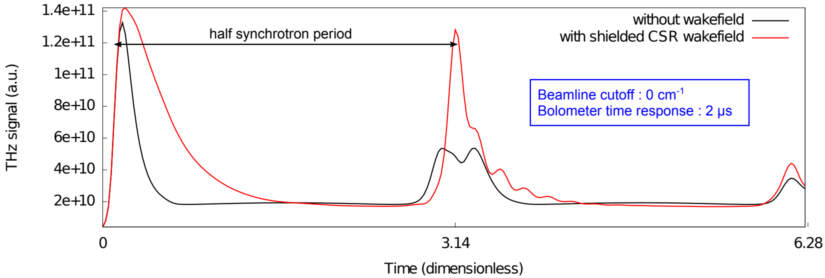


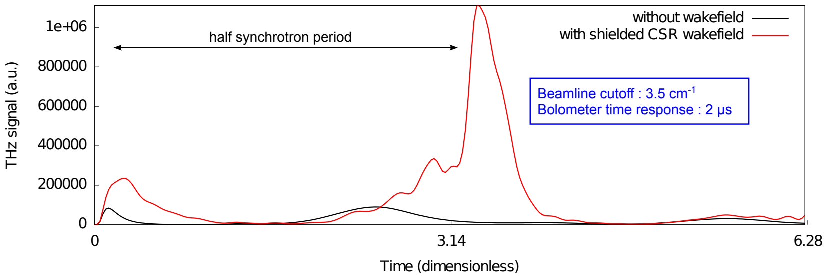
- Beamline cutoff : 0 cm^{-1}
- Bolometer time response : 2 μs

Typical simulated bolometer signal for an excitation at 1.5 cm^{-1}



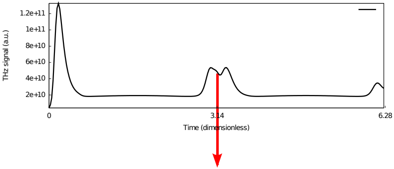
Typical simulated bolometer signal for an excitation at 1.5 cm^{-1}

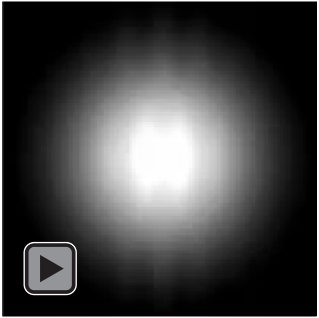




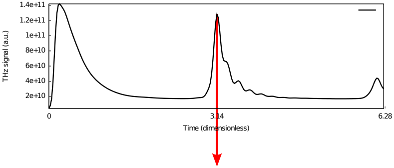
Longitudinal phase space for an excitation at 1.5 cm^{-1}

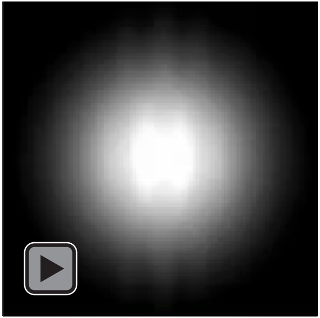
- without wakefield





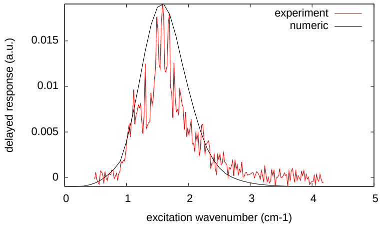
- with shielded CSR wakefield



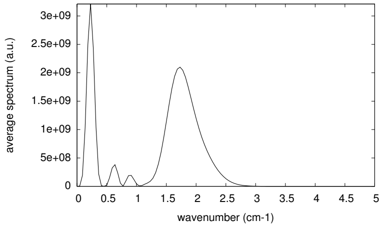


Resonance curve

- Maximum value of the delayed response



- Numerical average spectrum of the spontaneous CSR



- Experimental and numerical resonance wavenumber : 1.6 cm^{-1}
- Response at half synchrotron period :
  resonance curve at the characteristic wavenumbers of the system.

Conclusion

Experimental results

- Seeding of the microbunching instability with modulated laser pulses.
- Resonance curve at the characteristic wavenumber of the microbunching instability.

Numerical analysis

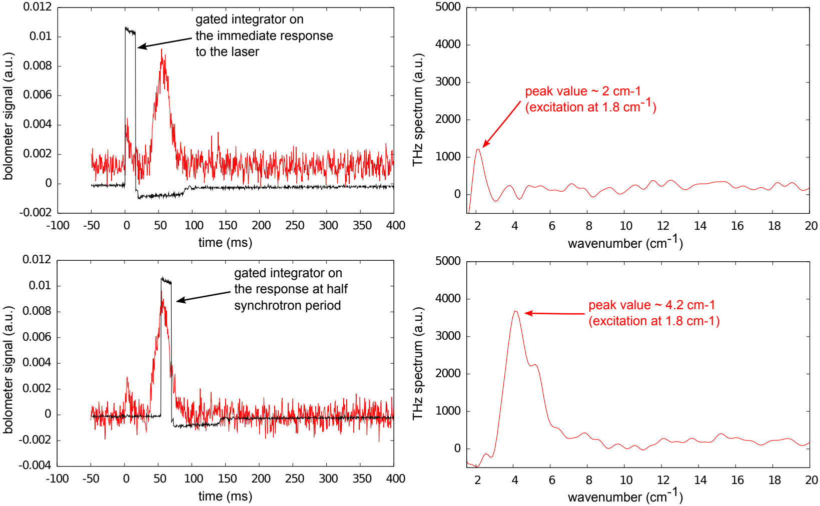
- Some agreements with a simple 1D model (VFP + shielded CSR wakefield), e.g., the resonance wavenumber, the response at half synchrotron period
- Differences in the amplitude of the responses, e.g., ratio immediate/delayed response

Next steps

- Improvement of wakefield models. [Agoh and Yokoya, Phys. Rev. STAB 7, 054403 (2004)] [Stupakov and Kotelnikov, Phys. Rev. STAB 12, 104401 (2009)]
- Taking into account the transverse aspect and other experimental aspects, e.g., the beamline response.

BACKUP

Experimental spectra



- Detected wavenumber at half synchrotron period is 2 times larger than initial excitation.
- Do we detect the harmonic of the modulation ? ?

Temporal spectra (numerical) for an excitation at 1.5 cm^{-1}