Studies on Coherent Synchrotron Radiation at SOLEIL

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ESLSW XVIII

Plan

1. THz CSR

2. Echo on storage rings : femtosecond short-wavelength CSR pulses

Outline

Introduction

- 12/2008 : first observation of THz CSR on the beamline AILES in a low-α mode
- Since 04/2010 : dedicated study machine shifts with the following problematics :
  - THz CSR for user experiments ?
  - Limits of the storage ring in terms of CSR instability ?

Introduction

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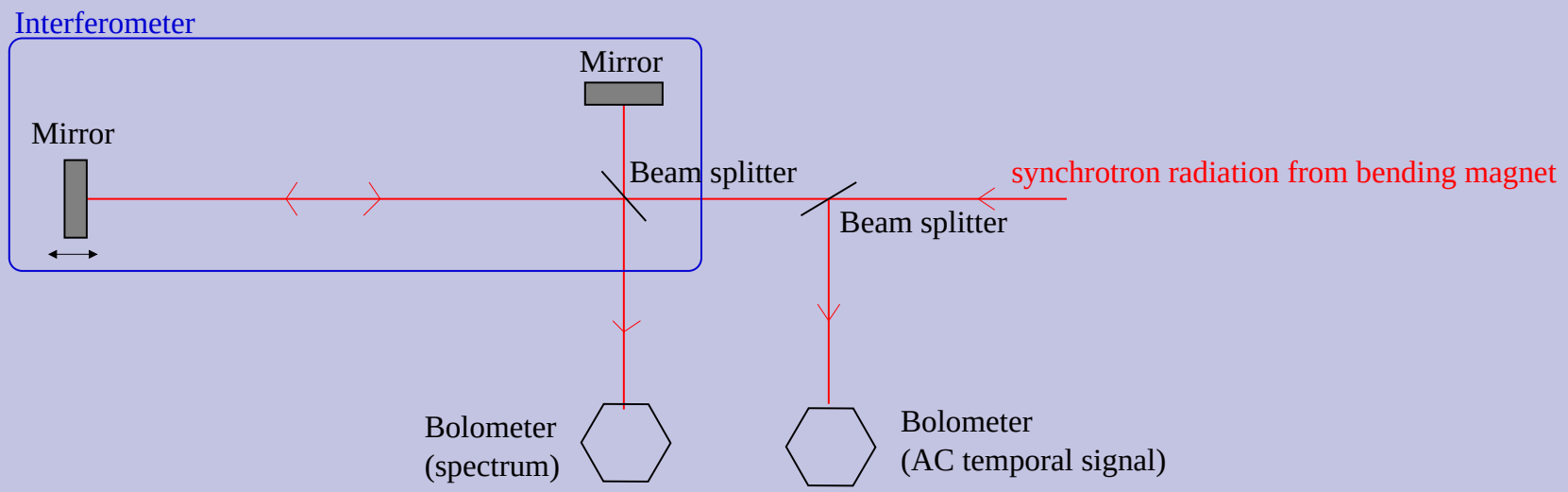
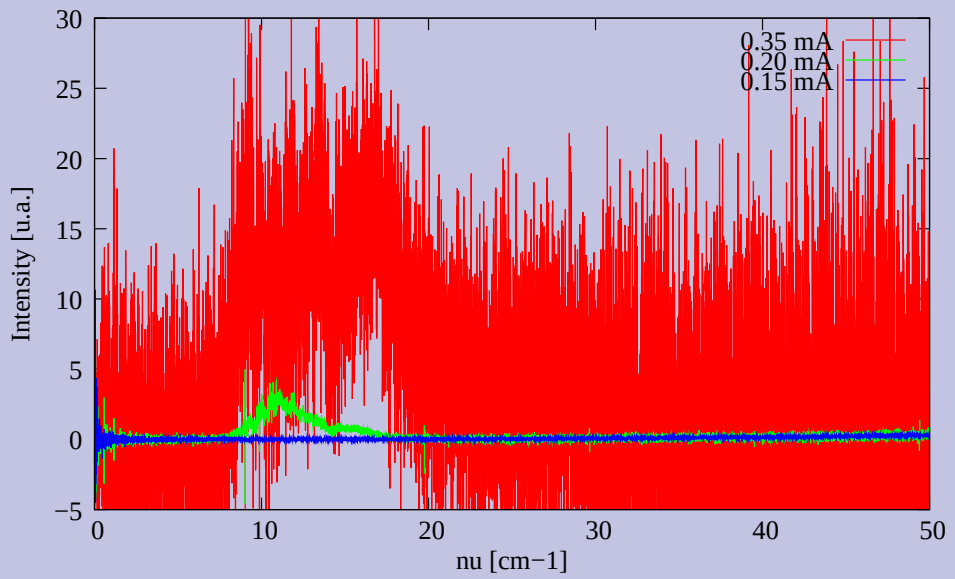
Experimental setup on the beamline AILES (THz and middle-far IR beamline)



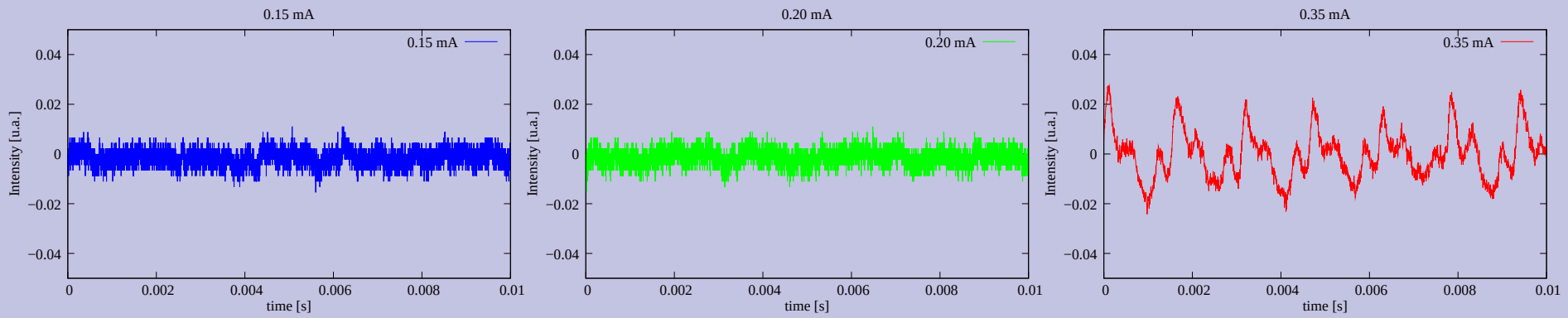
General behavior versus the current (ex : $\alpha/10$)

Associated spectrums



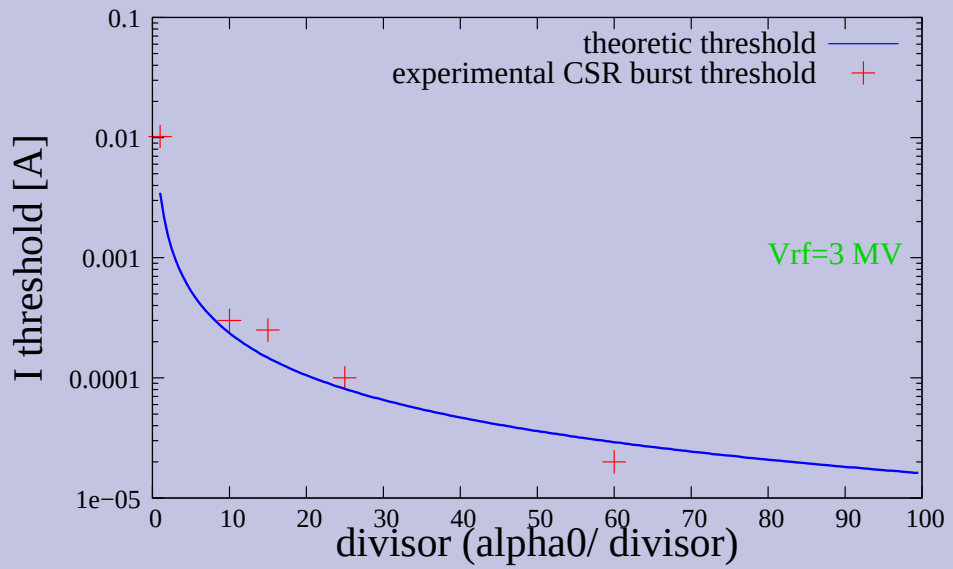
- $\alpha_0 \simeq 4.4 \times 10^{-4}$ (Synchrotron frequency$\simeq$ 4.5 kHz at $V_{rf} = 3$ MV)
- Bolometer time resolution $<$1 kHz
- Measured RMS e-bunch duration$\simeq$7 ps (theoritical at zero current$\simeq$5 ps)
- "Stable" and Bursts THz CSR observed at : BESSY-II, UVSOR-II, ANKA, DIAMOND, ELETTRA, etc.

Temporal signals



CSR burst threshold

Experimental points and analytical threshold



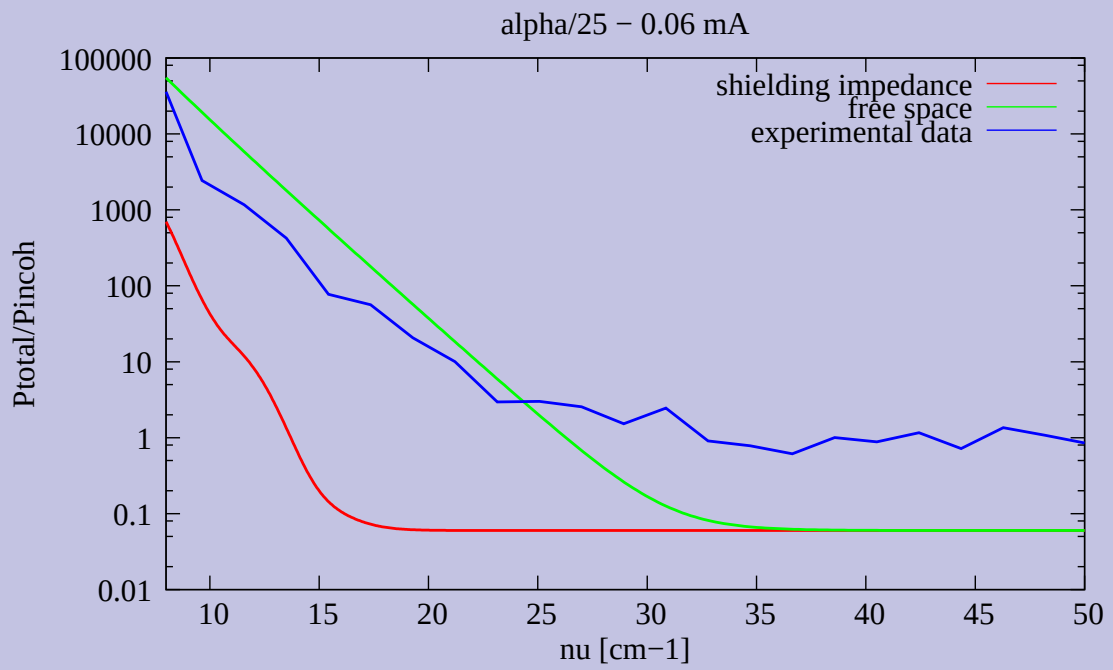
S. Heifest and G. Stupakov analytical threshold [PRST-AB 5 (2002) 064401]

$$\boxed{kR < 2\Omega^{3/2}} \quad \text{with} \quad \Lambda = \frac{IR}{\alpha\Lambda(\sigma_E/E_0)^2 I_A < R >}, < R > = C/2\pi, I_A = 17.5 \ kA$$

$$\text{and} \quad k = 2\pi/\sigma_{z0}$$

"Stable" CSR

$P_{total}/P_{incoherent}$



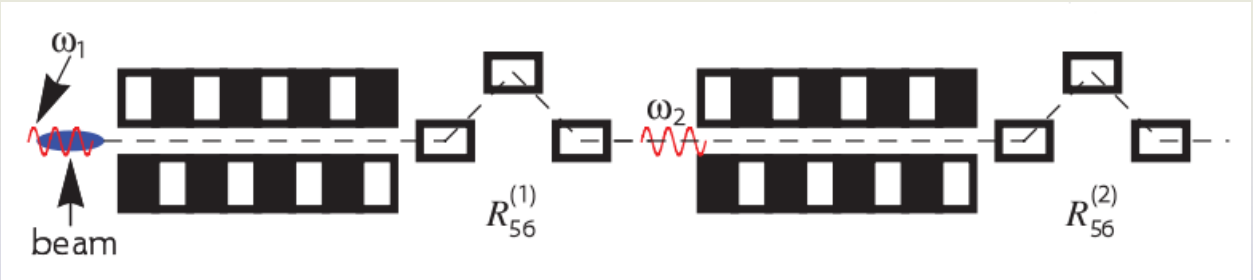
- $P_{incoherent}$ @ 400 mA
- P_{total} @ 24 mA (0.06×400 mA)
- Resolution : 0.1 cm^{-1}
- Bolometer time resolution<1 ms

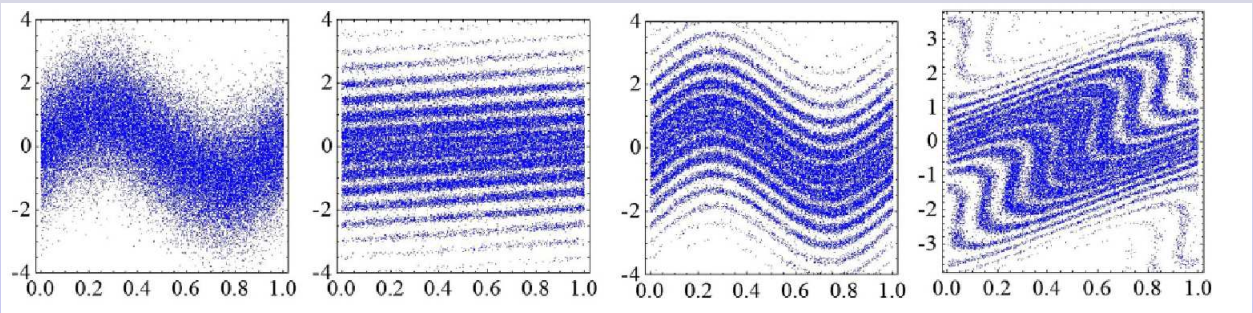
- Stationary Haissinski solution with free-space impedance model and parallel plate impedance model
  [J.B. Murphy et. al., Particule Accelerators 57, 9(1997)] [Y.S Derbenev et. al., TESLA-FEL 95-05 (1995)] [F. Sannibale et al., Phys. Rev. Lett. 93, 094801 (2004)]
- Distance between parallel plates : 2 × 1.25 cm, bending magnet radius : 5.39 m

Outline

Echo-enable harmonic generation on FEL

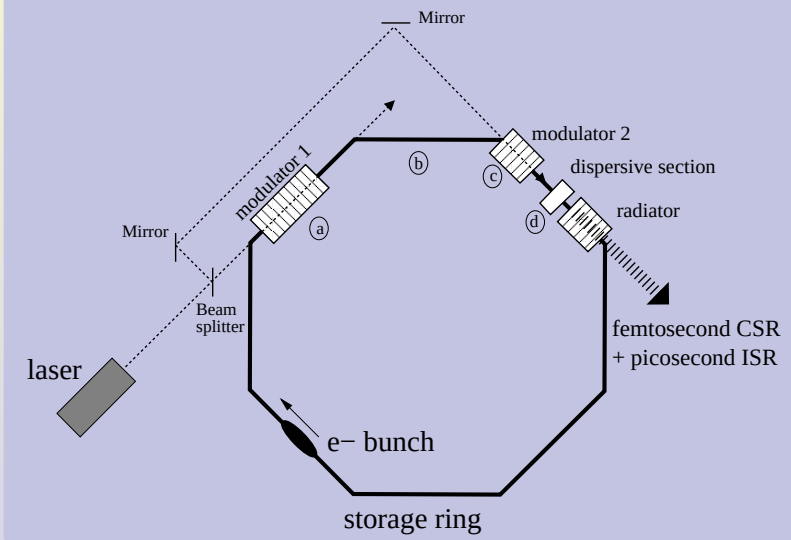
- Principle : G. Stupakov, Phys. Rev. Lett. 102, 074801 (2009)



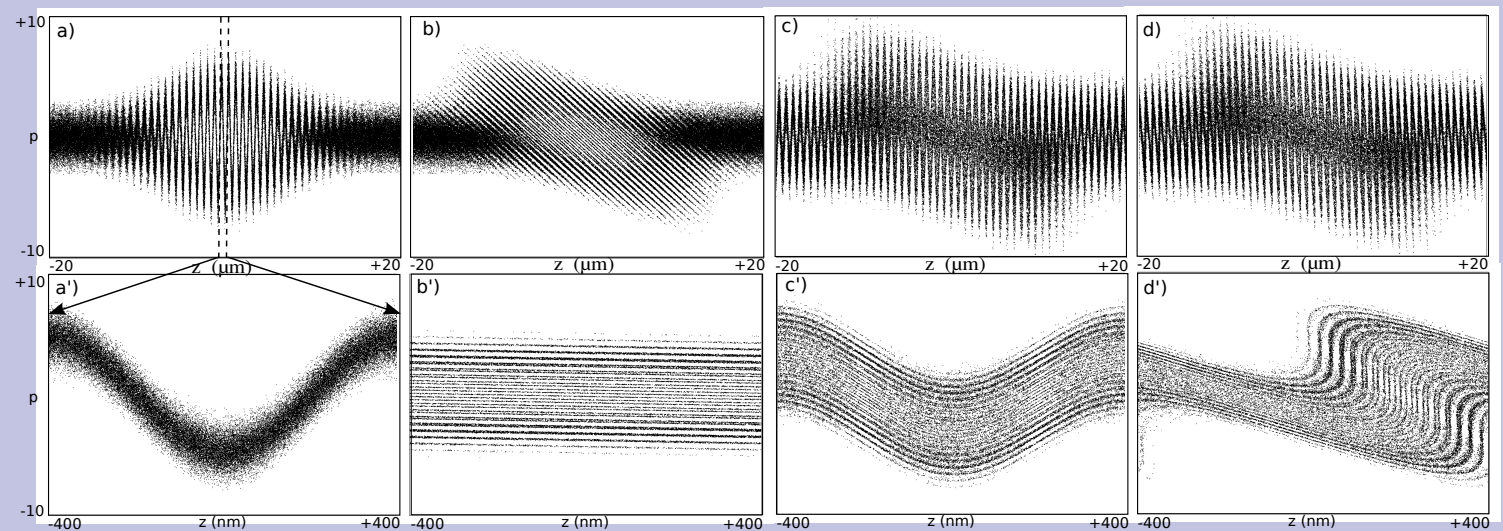


- Proof-of-principle experiment : D. Xiang et. al., Phys. Rev. Lett. 105, 114801 (2010)

Outline

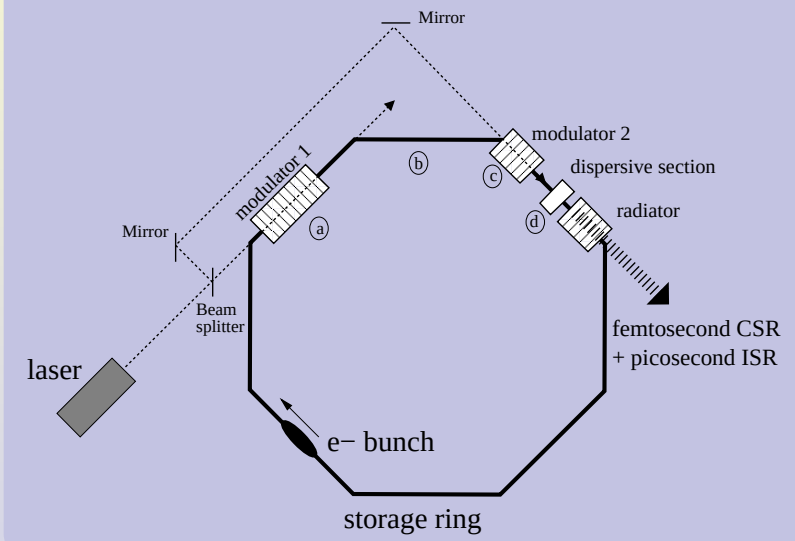


Longitudinal phase space (from 6D tracking simulation including noise from ISR)

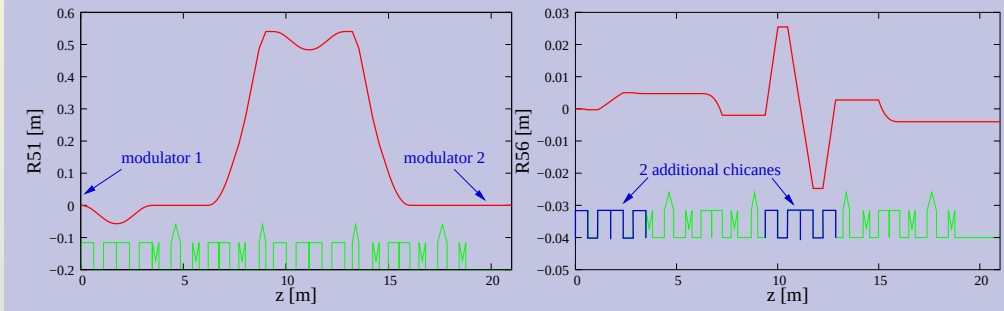


Echo on storage ring : principle

Outline

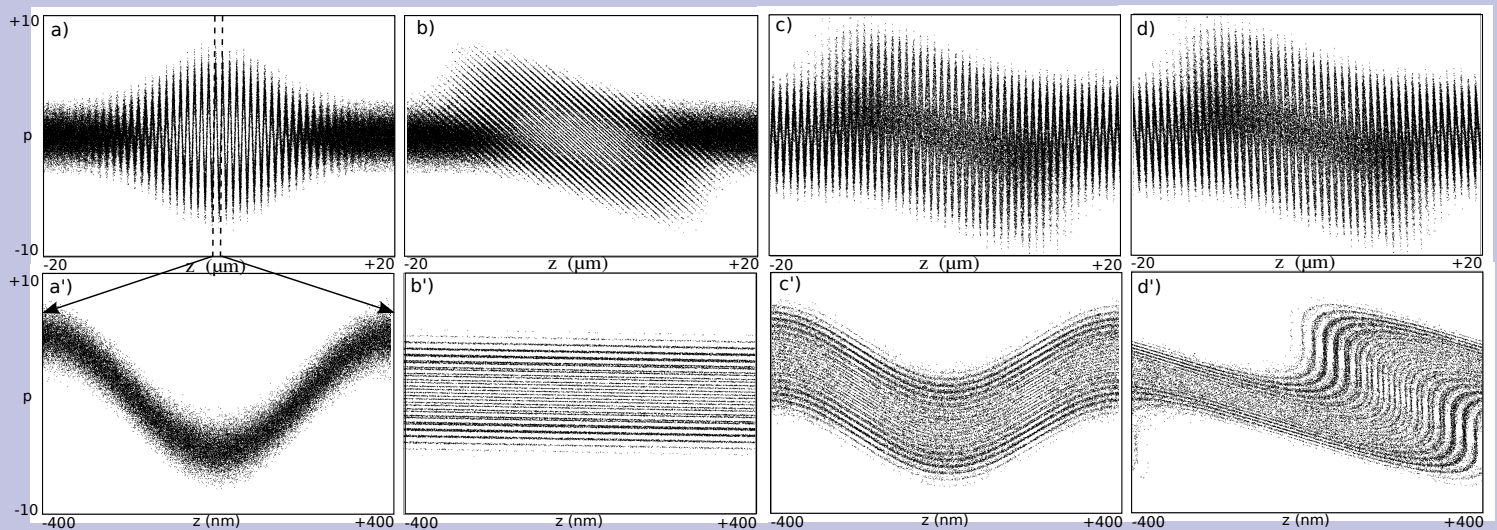


Optics between the two modulators

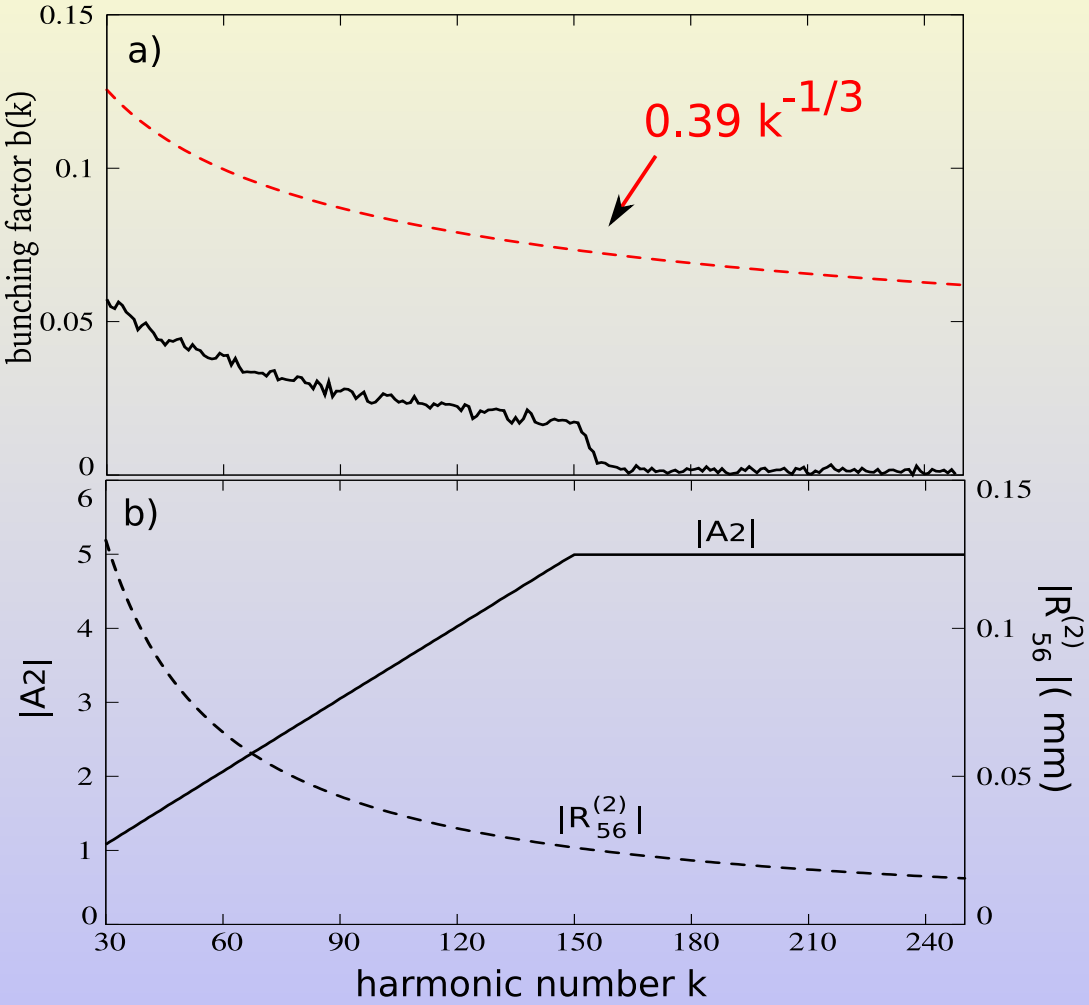


- "zero" transverse dispersion :
  $\Rightarrow$ Chasman-Green lattice
- Control of longitudinal dispersion :
  $\Rightarrow$ additional chicanes

Longitudinal phase space (from 6D tracking simulation including noise from ISR)



Bunching factor versus wavelength



- $b(k) = \frac{1}{N} | < \rho(z) > e^{ikz2\pi/\lambda_L} > |$
- TEMPO beamline undulator ($\lambda_u = 80$ mm, $N_u = 19$, 27.6-0.8 nm, $k \in [29 : 967]$)
- First energy modulation amplitude $A_1 = 5$ (unit of σ_E)
- $R_{56}^{(1)} = 4$ mm

$$b(k) = \left| J_{k+1}[kA_2B_2]J_1[A_1(B_1 - kB_2)] \times e^{-\frac{1}{2}[B_1 - kB_2]^2} \right| \quad [D.\ Xiang\ and\ G.\ Stupakov,\ PRSTAB\ (2009)]$$

$$b(k) \simeq 0.39k^{-1/3} \quad optimized\ bunching\ factor [D.\ Xiang\ and\ G.\ Stupakov,\ PRSTAB\ (2009)]$$

Emitted peak power

- Analytical formula

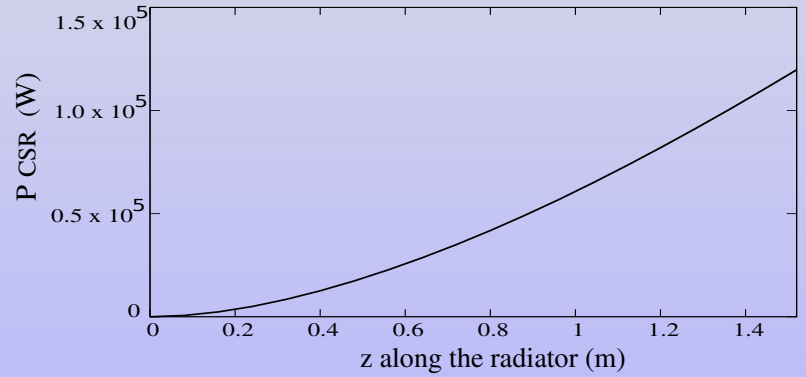
$$P_{CSR} = \pi\alpha\hbar\omega \frac{K^2}{1+K^2/2}[JJ]^2 \frac{I_{\rm peak}}{e} n_e b^2 \sqrt{f_2}.$$

[Z. Huang and K.-J. Kim, PAC'99]

- $n_e = \frac{I_{\rm peak}\lambda_r N_u}{ce}$,
- $f_2 = (\sigma_r\sigma_{r'})^2/(\sqrt{\sigma_r^2+\sigma_x^2}\sqrt{\sigma_{r'}^2+\sigma_{x'}^2}\sqrt{\sigma_r^2+\sigma_y^2}\sqrt{\sigma_{r'}^2+\sigma_{y'}^2})$,
- $\sigma_r = \sqrt{2\lambda_r\lambda_u Nu}/4\pi$,
- $\sigma_{r'} = \sqrt{\lambda_r/2\lambda_u N_u}$.

@ 27.5 nm (800/30 nm) with $b = 5\%$ and $I_{peak} = 138$ A, $\underline{P_{CSR} \simeq 187 \text{ kW}}$

- With GENESIS :



$\underline{P'_{CSR} \simeq 120 \text{ kW}}$

Comparison with slicing power and signal-to-noise ratio

- Slicing power P_{ISR}

$$P_{ISR} = \dot{N}_{phot}\hbar\omega \times \eta \ (\eta: \textit{ percentage of electrons involved in the fs light pulse})$$

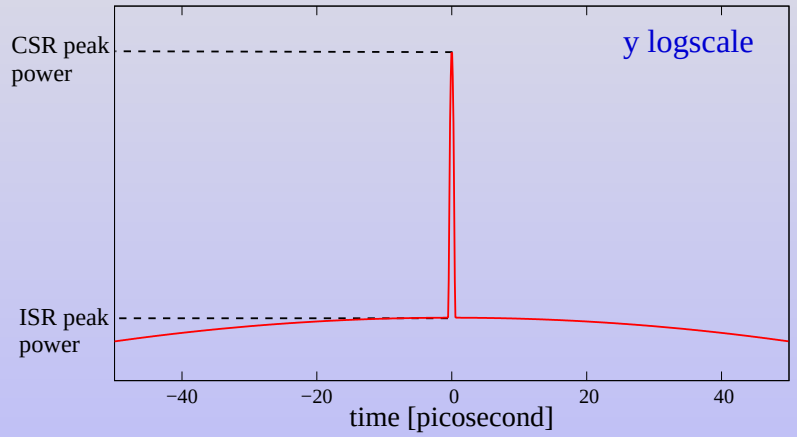
$$\dot{N}_{ph}(\omega) = \pi\alpha N_u \frac{\Delta\omega}{\omega}\frac{I_{\rm peak}}{e}\frac{K^2[JJ]^2}{1+K^2/2}$$

$P_{ISR} \simeq$0.135 W at $\lambda_r = 26.7$ nm with $\Delta\omega/\omega = 0.05\%$ and $\eta = 0.1$

$$P_{CSR}/P_{ISR} \simeq 10^6$$

- Signal-to-noise-ratio S/N

$$S/N = \frac{P_{CSR} \times \sigma_{L1}\ \eta\ c}{P_{ISR} \times \sigma_z} = \frac{n_e b^2\sqrt{f_2}\sigma_{L1}c}{\sigma_z} N_u \frac{\Delta\omega}{\omega} \simeq 168$$



Submitted to Phys. Rev. Lett.

Conclusion

THz CSR

- Observation of THz CSR at SOLEIL
- Higher photon flux but lower stability compared to THz ISR and not "smooth" spectrum
  $\Rightarrow$ soon conclusion about the utility for user experiments
- Futur project : laser induced THz CSR (with slicing)

EEHG on storage ring

- Femtosecond CSR pulses at short-wavelength
- On the SOLEIL example : until 5 nm and with 6 orders of magnitude power increase compared to slicing at 27 nm
- No direct test possible at SOLEIL without moving presently installed undulators.
- To estimate experimental difficulty : study of the microstructure sensibility to magnetic errors.

Coordinate changes at each step

a	$p = p + A_1 \times e^{-\frac{z^2}{2(c\sigma_{L1})^2}} \cos(\frac{2\pi}{\lambda_L} z) \times e^{-\frac{x^2+y^2}{w_1^2}}$
b	$z \simeq z + p \times R_{56}^{(1)} \frac{\sigma_E}{E_0}$
c	$p = p + A_2 \times e^{-\frac{z^2}{2(c\sigma_{L2})^2}} \cos(\frac{2\pi}{\lambda_L} z) \times e^{-\frac{x^2+y^2}{w_2^2}}$
d	$z \simeq z + p \times R_{56}^{(2)} \frac{\sigma_E}{E_0}$

SOLEIL parameters used in our study

Nominal energy E_0 (GeV), energy spread σ_E (MeV)	2.75, 2.79
Bunch dimensions σ_z (mm), σ_x (μm), $\sigma_{x'}$ (μrad)	10.5, 147, 33
Bunch dimensions σ_y (μm), $\sigma_{y'}$ (μrad)	10.0, 4.8
Peak current I_{peak} (A)	134
Radius R (m) and length L (m) of a bending magnet	5.39, 1
Chicane length (m) and field (T)	0.65, 0.7
Modulator 1&2 period length (mm)	150
Modulator 1&2 number of periods	13
Radiator period length λ_u (mm)	80
Radiator number of periods N_u	19
Laser wavelength λ_L (nm)	800
Maximum energy laser pulse (mJ)	5
RMS laser pulse length σ_{L1} (fs), σ_{L2} (fs)	43, 118