France-Ukraine collaboration on advanced beam diagnostics

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UNIVERSITÉ PARIS SUD
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LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

cnrs dépasser les frontières
IN2P3 Les deux infinis

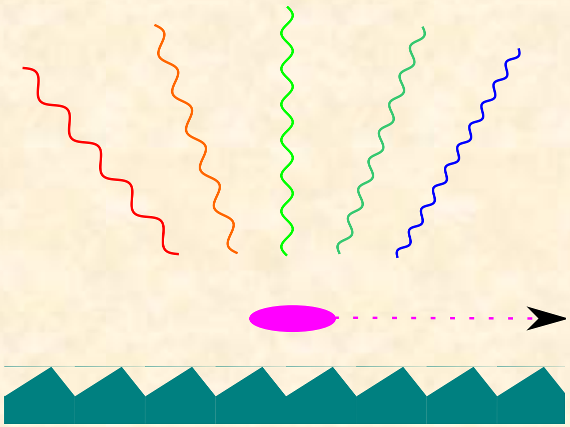
Work supported by seed funding from Université Paris-Sud, program « Attractivité » and by the ANR under contract ANR-12-JS05-0003-01.

Bunch length measurement at LAL

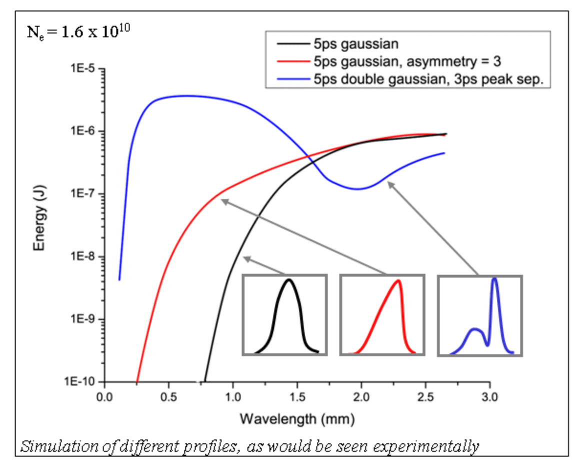
- Some accelerators need ultra-short bunches (fs range).
- Example: Free Electron Lasers and plasma driven accelerators.
- LAL has received funding to develop a device to measure bunch length using Coherent Smith-Purcell radiation.
- The work is divided in several tasks, some theoretical and some more experimental.

- LAL group: 1 faculty, 1 post-doc, 1PhD student

Coherent Smith-Purcell radiation



- Electrons passing near a grating induce the emission of (visible) radiation.
- For ultra short pulses part of the radiation is emitted coherently.
- The wavelength (energy) spectrum encodes the Fourier transform longitudinal profile of the bunch. => can de used as a diagnostic.
- First prototype built by the University of Oxford and tested on picosecond bunches.



Simulation of different profiles, as would be seen experimentally

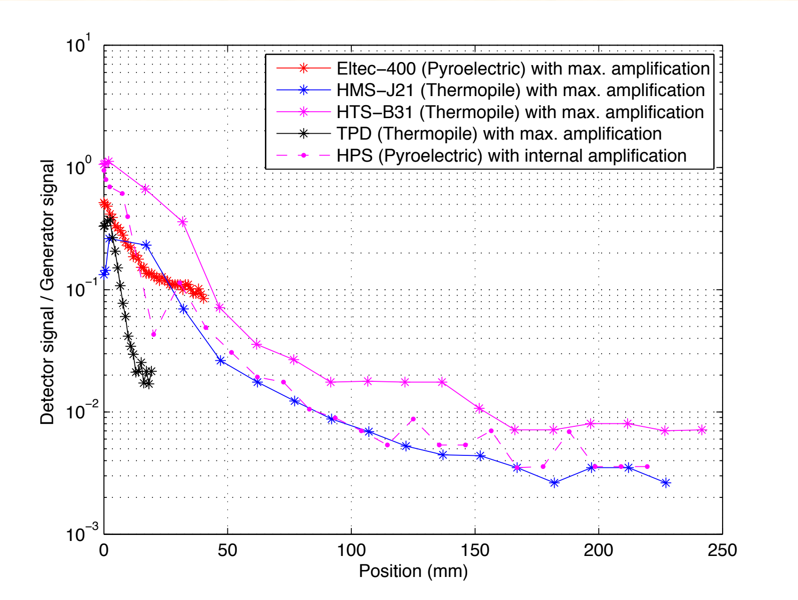
$$\left(\frac{dI}{d\Omega d\omega}\right)_{N_e}(\Omega,\omega) \approx \left(\frac{dI}{d\Omega d\omega}\right)_{sp}(\Omega,\omega)\cdot\left[N_e + N_e(N_e-1)\,|F(\omega)|^2\right]$$

R&D tasks (grant)

- Several R&D tasks have been identified as part of the grant received from ANR:
  - simulations:
  * Signal yield
  * Interferences (Maksym Malovytsia, Kharkiv)
  - detectors tests (Olena Karacheban, Kyiv) and acquisition electronics (Vitalii Khodnevich, Kyiv)
  - experimental tests at several facilities (SLAC, SOLEIL, Frascati, Lund,…)
  - phase recovery (Vitalii Khodnevich, Kyiv)

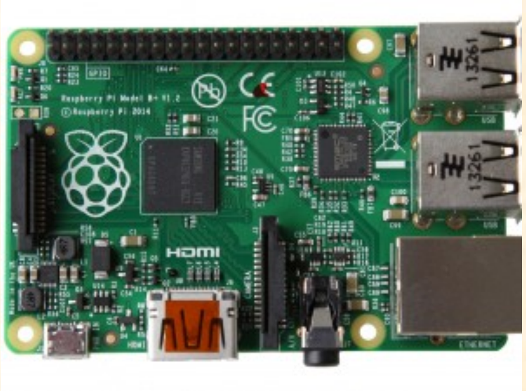
Wavelength and detectors

- This diagnostic is being developed for classical and novel accelerators.
- For a ps beam the CSPR is in the mm range.
- For 100fs beam the CSPR is in the far IR/THz range.
- We use pyroelectric detectors: good wavelength coverage but low responsivity (could use other detectors where available).
- However the signal needs to be strongly amplified.



Contribution from Olena Karacheban, Kyiv

Detectors amplification

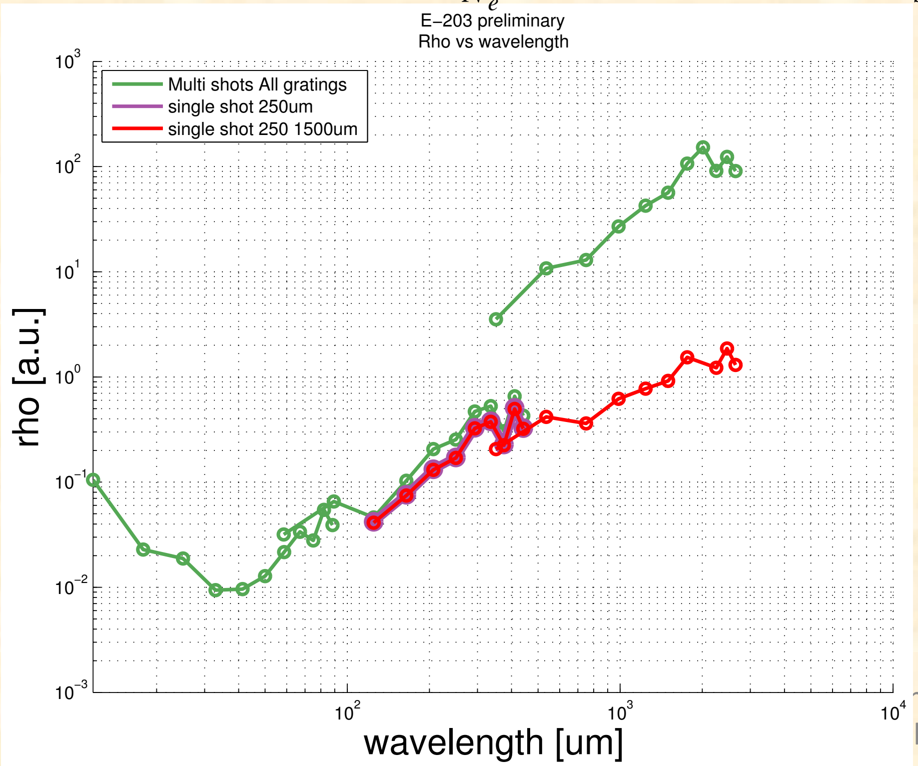


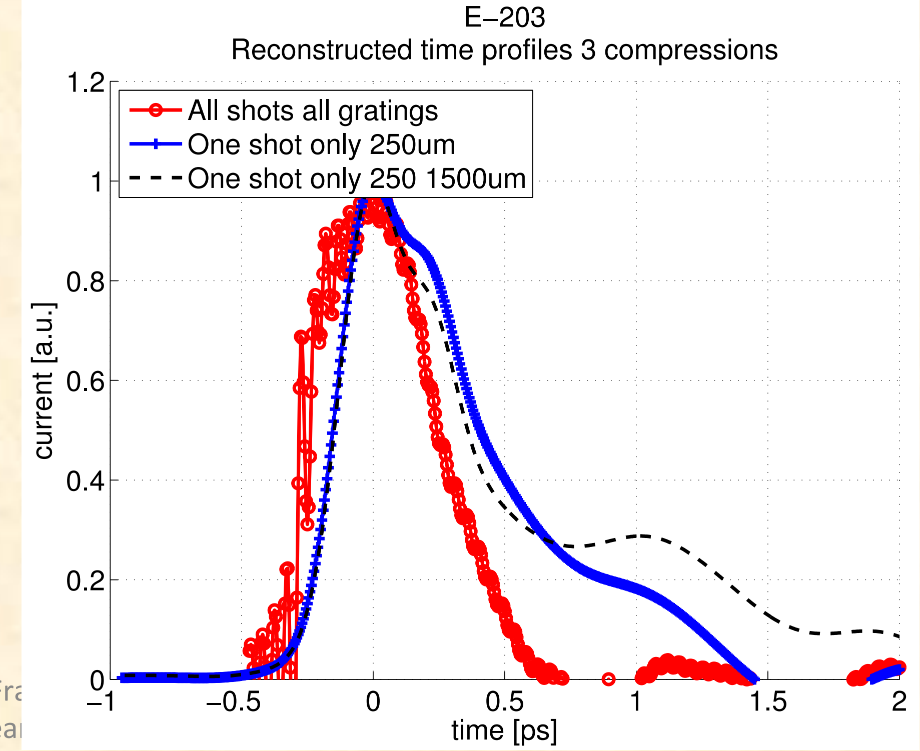
- The signal expected is very weak
  => strong amplification needed.
- For the detector to work correctly a large number of channels is needed.
- Need a system easy to install in a particle accelerator and cheap.
- Vitalii has built an amplifier matched to our detectors.
- Architecture based on a raspberry pi + 8 channels (ADC).

Bunch reconstruction from CSPR

- CSPR spectrum contains the square of the FT of the bunch profile.
  => Need to recover the phase of the FT.
  => Currently use Kramers Kronig relation but needs further studies.

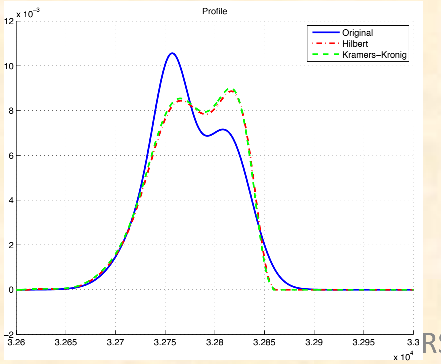
$$\left(\frac{dI}{d\Omega d\omega}\right)_{N_e}(\Omega,\omega) \approx \left(\frac{dI}{d\Omega d\omega}\right)_{sp}(\Omega,\omega)\cdot [N_e + N_e(N_e - 1)\,|F(\omega)|^2]$$

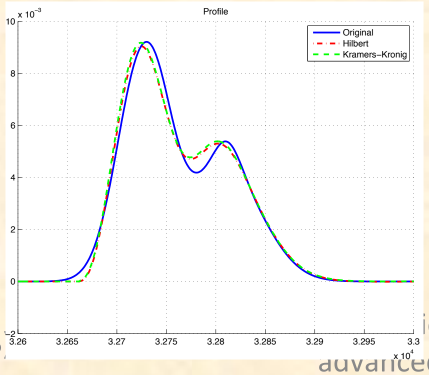


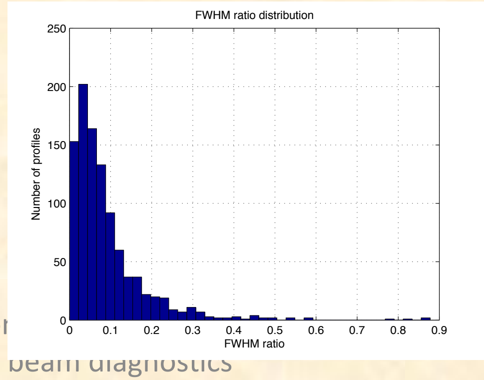


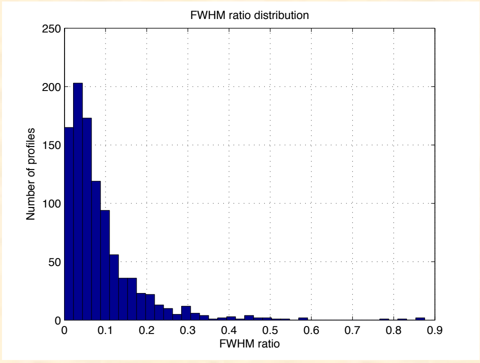
Results on the collaborative tasks: Phase recovery

- Need to demonstrate that our method is valid and gives the correct reconstruction.
- Extensive simulations (> 1000 profiles).
- Demonstrates good agreement + improvement of the method using Hilbert transform.
- Now investigating another method with the expectation of even better results.









Recent publication: IPAC 2014

STUDY OF PHASE RECONSTRUCTION TECHNIQUES APPLIED TO SMITH-PURCELL RADIATION MEASUREMENTS*

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Oleg Bezshyyko, Vitalii Khodnevych, Taras Shevchenko National University of Kyiv, Ukraine

Abstract

Measurements of coherent radiation at accelerators typically give the absolute value of the beam profile Fourier transform but not its phase. Phase reconstruction techniques such as Hilbert transform or Kramers Kronig reconstruction are used to recover such phase. We report a study of the performances of these methods and how to optimize the reconstructed profiles.

the imaginary part of an analytic function $\varepsilon(\omega)$ from its real part and vice versa.

To recover the phase from the amplitude, the function should be written as: $log(\varepsilon(\omega)) = log(\rho(\omega)) + i\Theta(\omega)$ with $\rho(\omega)$ its amplitude and $\Theta(\omega)$ its phase. The Kramers-Kronig relations can then be applied as follows:

$$\Theta(\omega_0) = \frac{2\omega_0}{\pi} P \int_0^{+\infty} \frac{ln(\rho(\omega))}{\omega_0^2 - \omega^2} d\omega$$

- Paper contributed to IPAC'14 + arXiv.org 1407.0741
- To be submitted to PRST-AB.

Outlook

- Bunch length measurements at modern accelerators is a difficult challenge.
- Several of the key tasks to address this challenge at LAL have been done by Ukrainian students (key contributions).
- Fruitful collaboration (1 conference proceeding => paper).
- Looking forward to continuing this collaboration in the coming years.