Progress on the study of Smith-Purcell radiation as bunch length diagnostic

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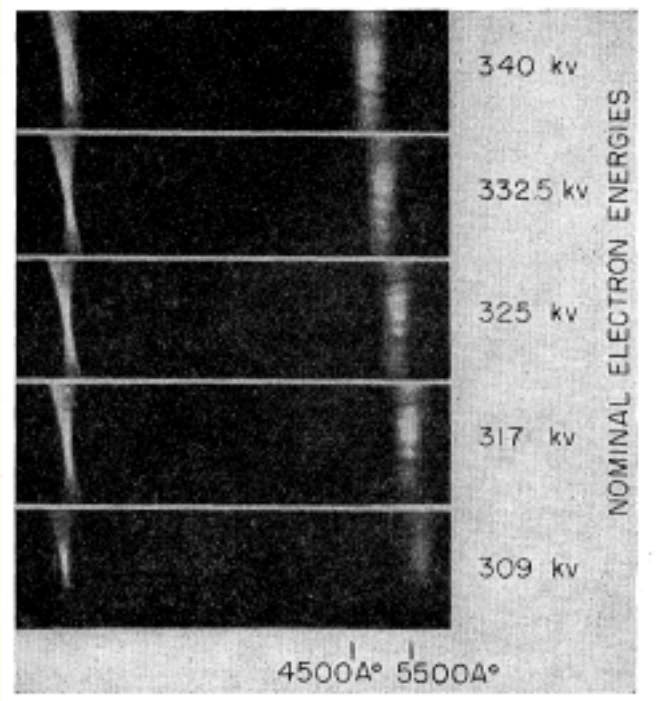
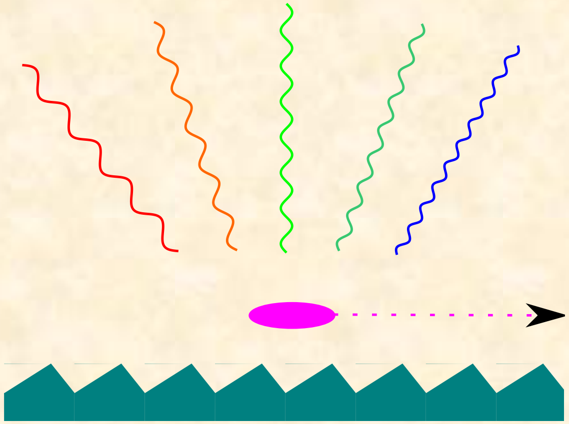
Work supported by seed funding from Université Paris-Sud, program « Attractivité » and by the ANR under contract ANR-12-JS05-0003-01.

Smith-Purcell radiation

- Discovered experimentally in 1953 by Smith and Purcell.
- Electrons passing near a grating induce the emission of (visible) radiation.
- *Radiation is dispersed spectrally.*
- S.J. Smith and E.M. Purcell, Phys. Rev. **92**, pg. 1069, (1953)
- 300 keV electrons to emit in the visible wavelengths (d = 1.67 um)
- Theta is the azimuthal angle.





$$\lambda = \frac{\ell}{n}\left(\frac{1}{\beta} - \cos\theta\right)$$

SP radiation and bunch profile

- The intensity of the radiation depends on the distance between the bunch and the grating.
- It depends also on the pitch of the grating.
- For relativistic electrons the beam energy is not very important.

$$\left(\frac{dI}{d\Omega}\right)_{sp} = 2\pi q^2 \frac{Z}{\ell^2} \frac{n^2\beta^3}{(1-\beta\cos\theta)^3} R^2 \exp\left(-\frac{2x_0}{\lambda_e}\right)$$

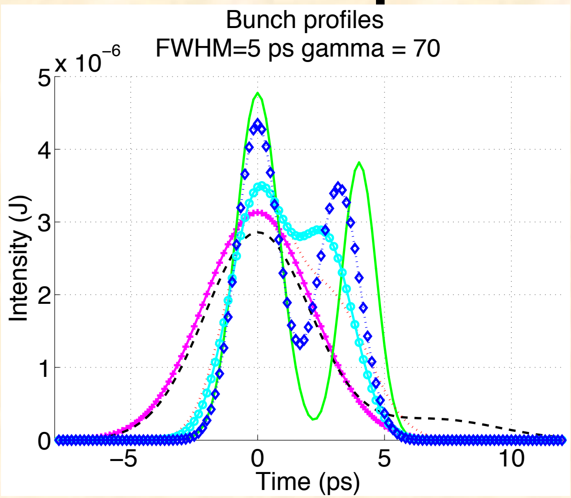
$$\lambda_e = \frac{\lambda}{2\pi}\frac{\beta\gamma}{\sqrt{1+\beta^2\gamma^2\sin^2\theta\sin^2\phi}}$$

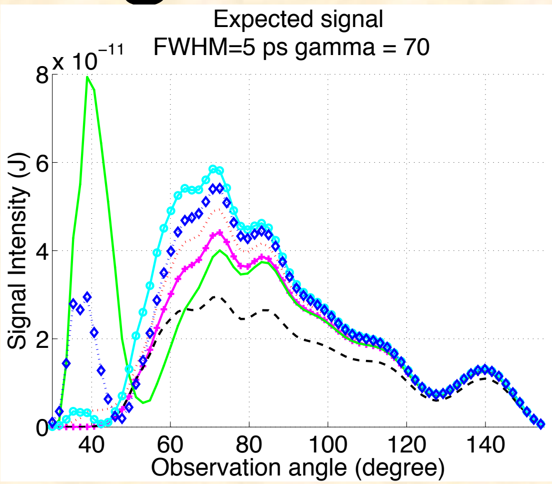
Coherent SP radiation

- Like many other radiative phenomena in EM, SP radiation can also be coherent at wavelength sufficiently longer than the bunch length.
- In both interpretation SP radiation depends on the shape of the electron bunch and the wavelength of the photons emitted encodes the Fourier transform of the electron bunch longitudinal profile.
- This means that for sufficiently short bunches the signal intensity is proportional to the square of the beam charge.

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

Coherent SPR as a longitudinal profile diagnostic





- Because Coherent SPR encodes the Fourier transform of the longitudinal profile, it can be used as a diagnostic.
- Such diagnostic requires a measurement of the SPR spectrum.

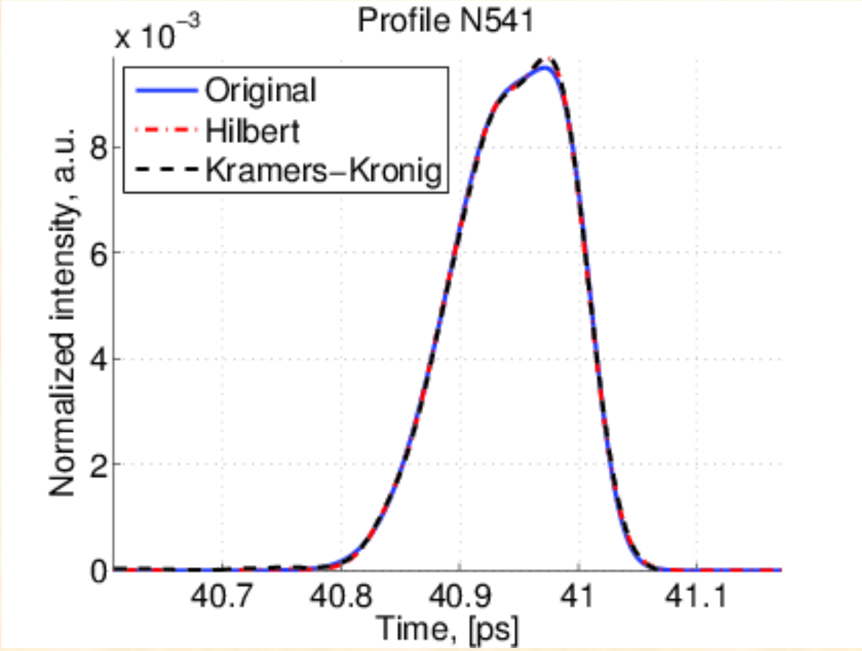
$$\left(\frac{dI}{d\Omega d\omega}\right)_{N_e}(\Omega,\omega)=\left(\frac{dI}{d\Omega d\omega}\right)_{sp}(\Omega,\omega)\cdot[N_e+N_e(N_e-1)|F(\omega)|^2]$$

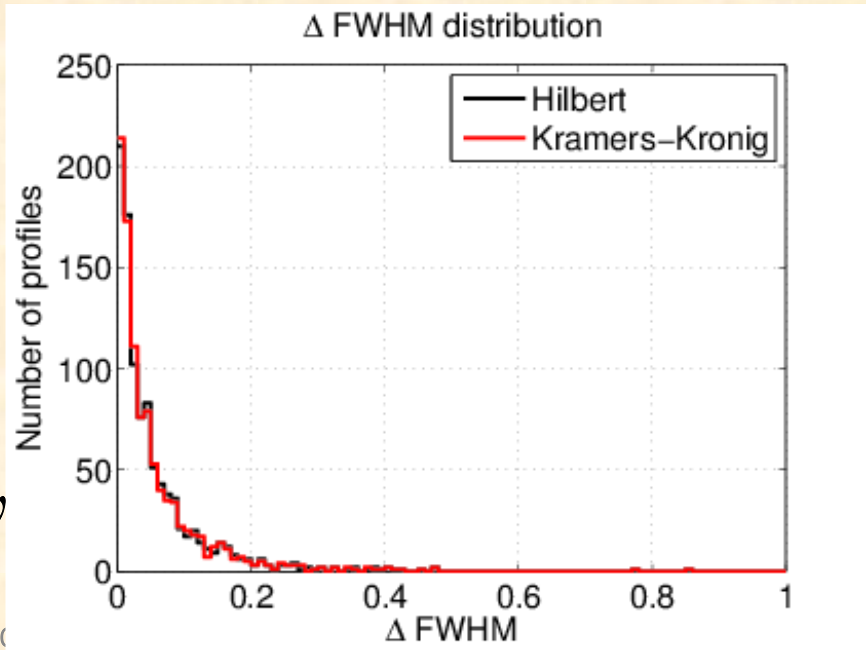
Work by Vitalii Hodnevych

Profile recovery

- Once the spectrum has been measured, one can attempt to recover the bema profile.
- To recover the profile we use the square of the Fourier Transform.
- However, the phase information is missing.
- Recovered using Kramers-Kronig or Hilbert relations.
- Work presented at IPAC'15.

$$\phi(\omega) = \frac{2\omega}{\pi}\int_0^{\omega} \frac{\ln\left[\rho(\omega)/\rho(\omega_0)\right]}{\omega_0^2-\omega^2} d\omega$$





CSPR as a longitudinal diagnostic: Work so far

- George Doucas from Oxford has been investigating CSPR as a longitudinal diagnostic for several years.
- Initial work on picosecond bunches
  => Test at FELIX (45MeV) in the Netherlands
  Phys. Rev. ST Accel. Beams 9, 092801 (2006)
  => Test at End Station A at SLAC (28.5 GeV)
  Phys. Rev. ST Accel. Beams 12, 032803 (2009)
- Extension to the femtoseconds range:
  E-203 Experiment at FACET 2011-2015 (Oxford, LAL, LANL, SLAC,…).
- SPESO at SOLEIL => characterisation of CSPR
- SP at CLIO => New geometry

E-203 Results

- Paper with profile reconstruction published in 2014.
- Further data taking in 2015 to study the polar distribution of the signal and its polarisation.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Reconstruction of the time profile of 20.35 GeV, subpicosecond long electron bunches by means of coherent Smith-Purcell radiation

Phys. Rev. ST Accel. Beams **17**, 052802 – Published 27 May 2014

H. L. Andrews, F. Bakkali Taheri, J. Barros, R. Bartolini, V. Bharadwaj, C. Clarke, N. Delerue, G. Doucas, N. Fuster-Martinez, M. Vieille-Grosjean, I. V. Konoplev, M. Labat, S. Le Corre, C. Perry, A. Reichold, and S. Stevenson

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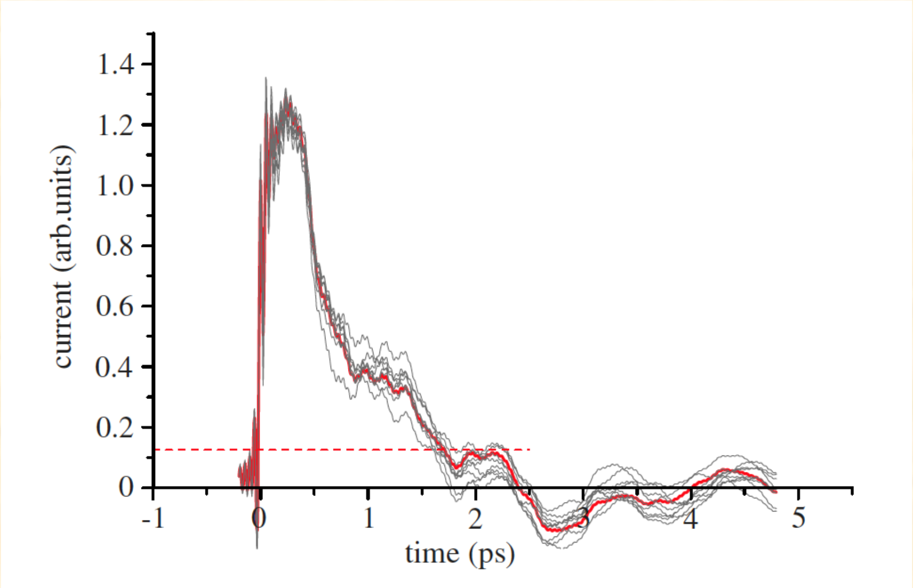
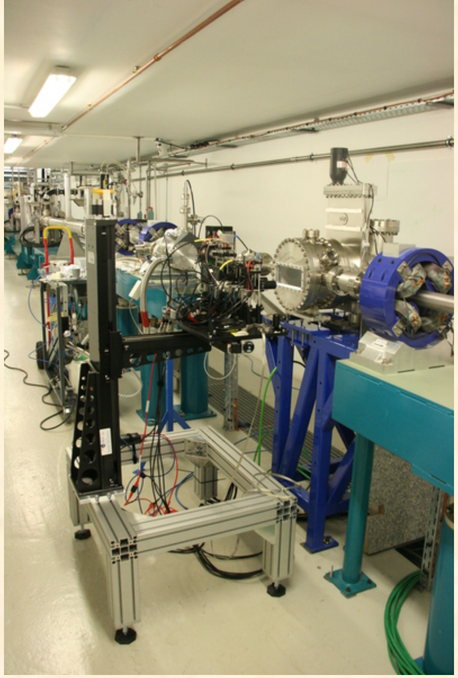
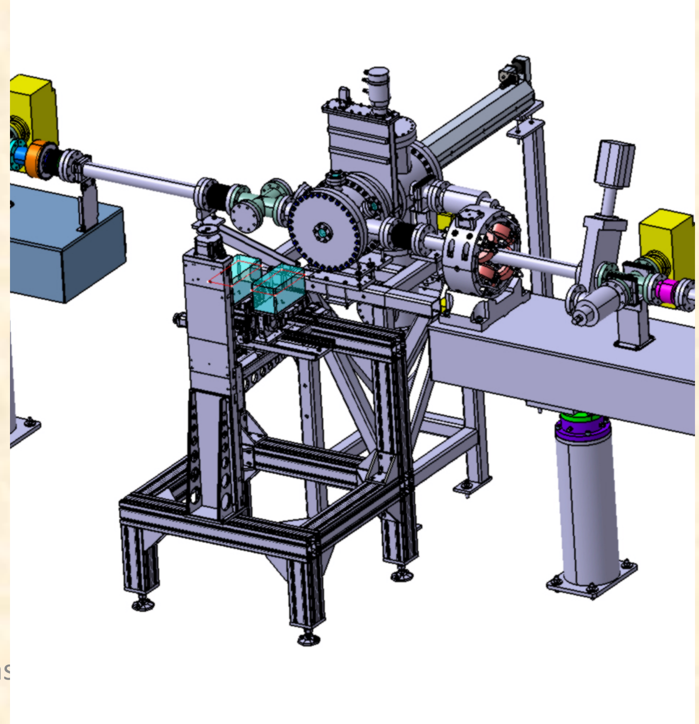


SPESO

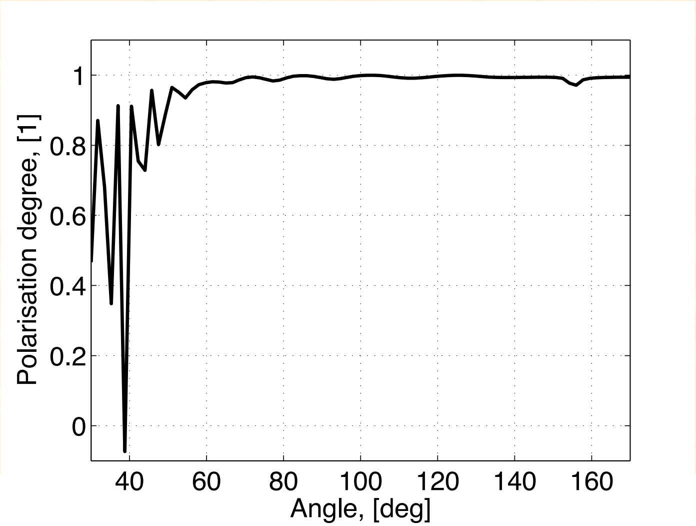
- To overcome the E-203 limitations, a Smith-Purcell test stand has been installed at the end of the SOLEIL Linac (gamma=200).
- A 5D robot can measure the radiation emitted at different positon and angles.
- A polarisation measurement system has been added to study the radiation polarisation.

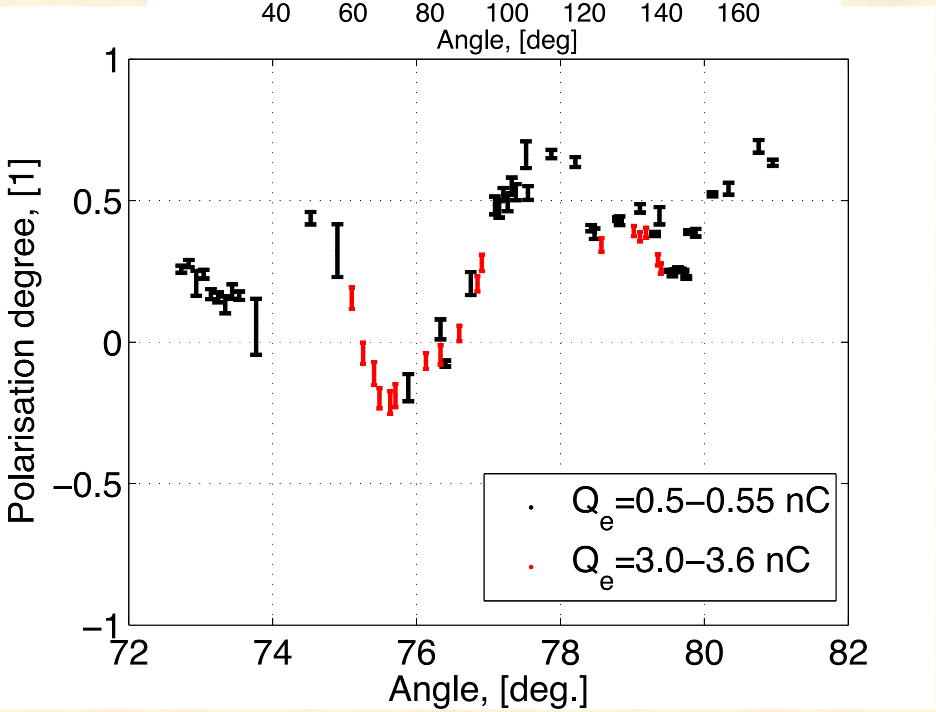




SPESO: polarisation measurements

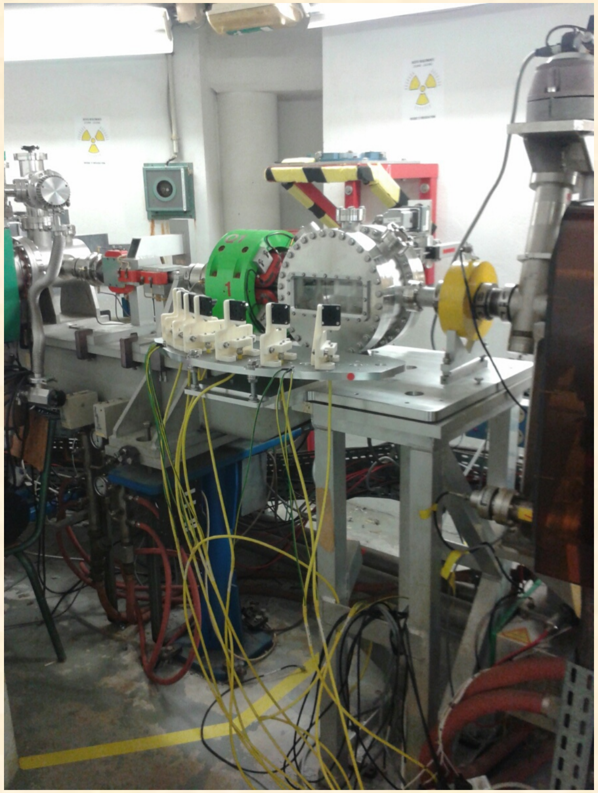
- Using the polariser installed in summer 2016 we have performed some polarisation measurements.
- The value is not as expected: polarisation is only about 50% when almost 100% was expected…
- However this value is consistent with what was observed at E-203 in 2012. => Is the polarization of SP radiation correctly described by the theory?

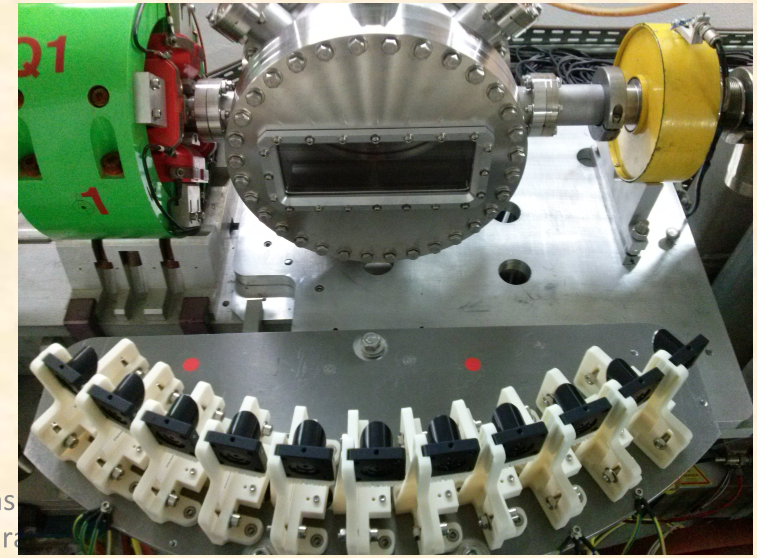




SP at CLIO

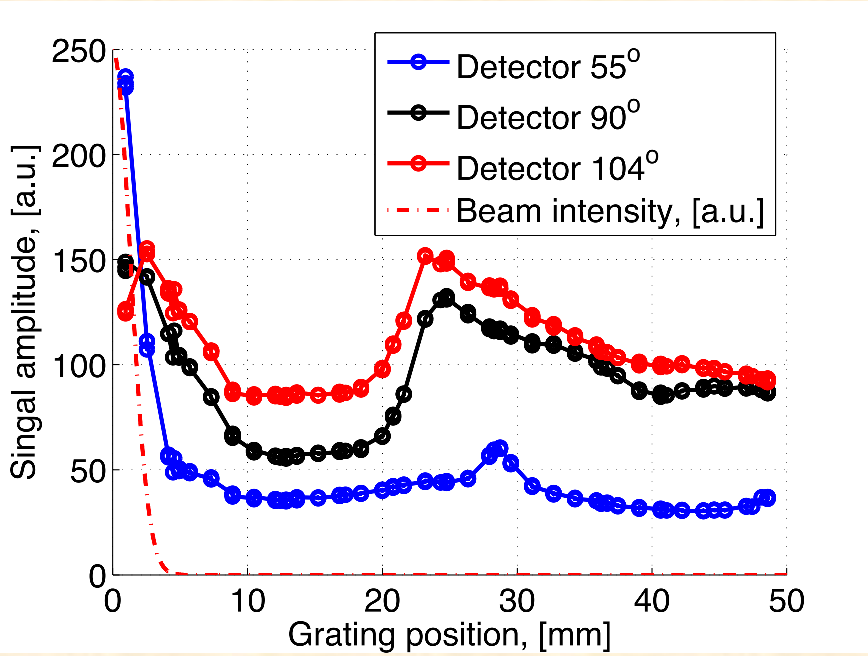
- CLIO is the French Free Electron Laser, located in Orsay (within LAL building).
- Bunch of the order of a few ps.
- Aim of the SP setup: test different geometries than at SPARC.

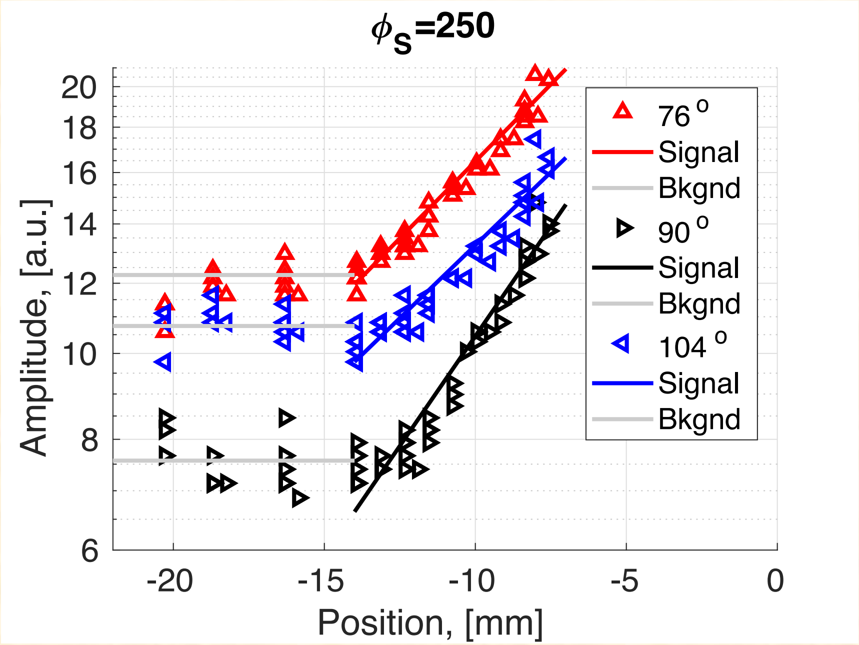




SP @CLIO: Results (1)

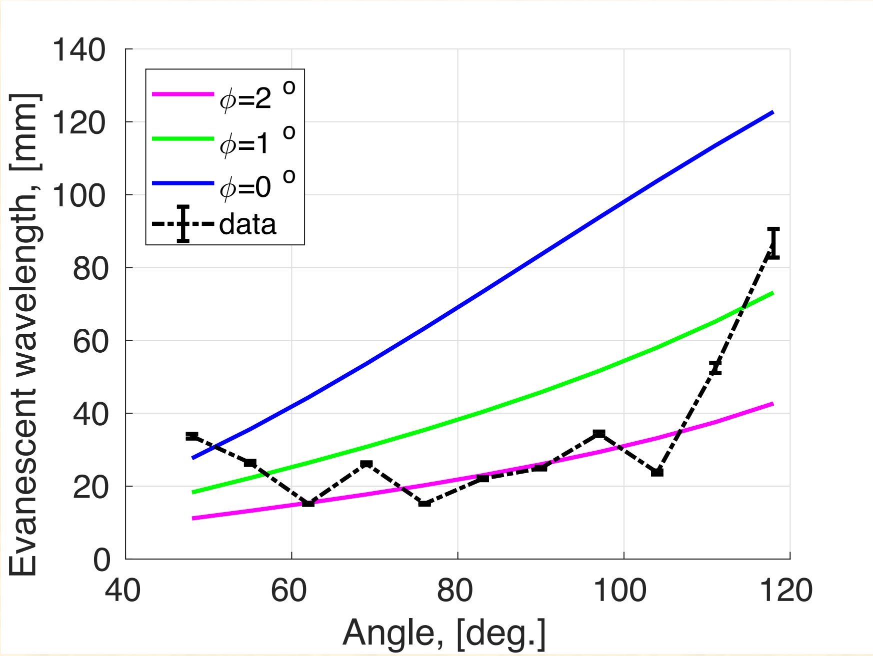
- First results presented at IPAC17.
- Significant progress during the master thesis of Vitalii Khodenych.
- Better understanding of the noise and its rejection.
- Good agreement between signal shape and predictions.

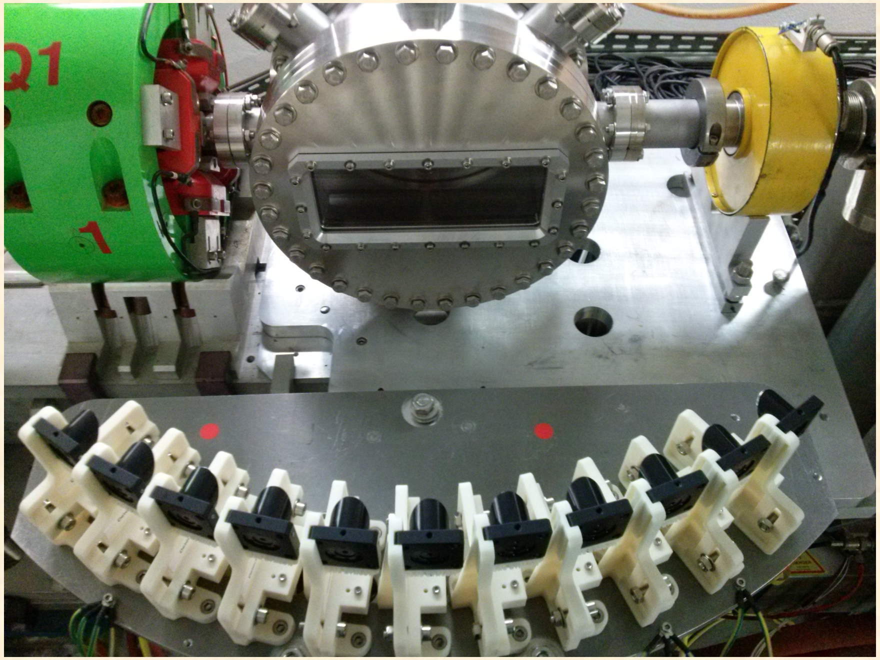




SP @CLIO: Results (2)

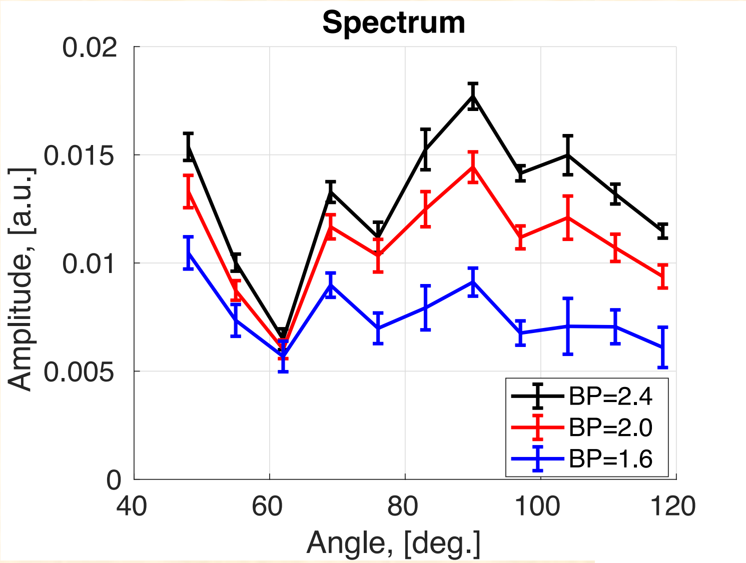
- Accuracy of the results allowed to detect a tilt of the detectors board.

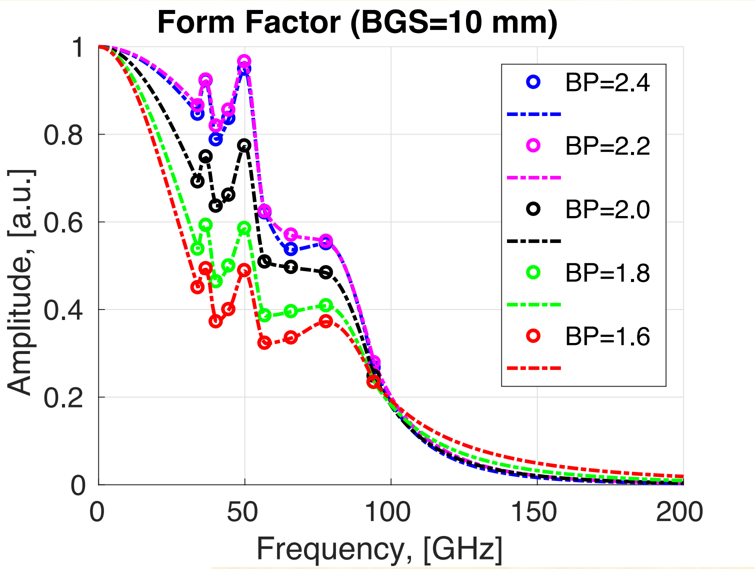


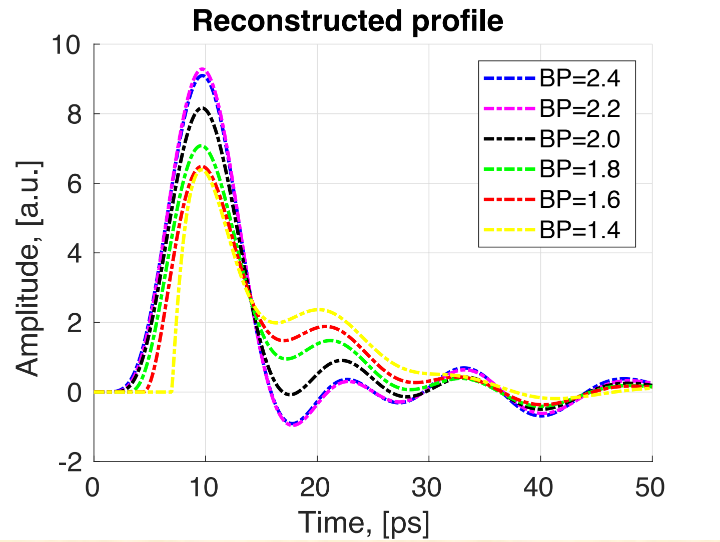


SP @CLIO: Results (3)

- Profile reconstruction

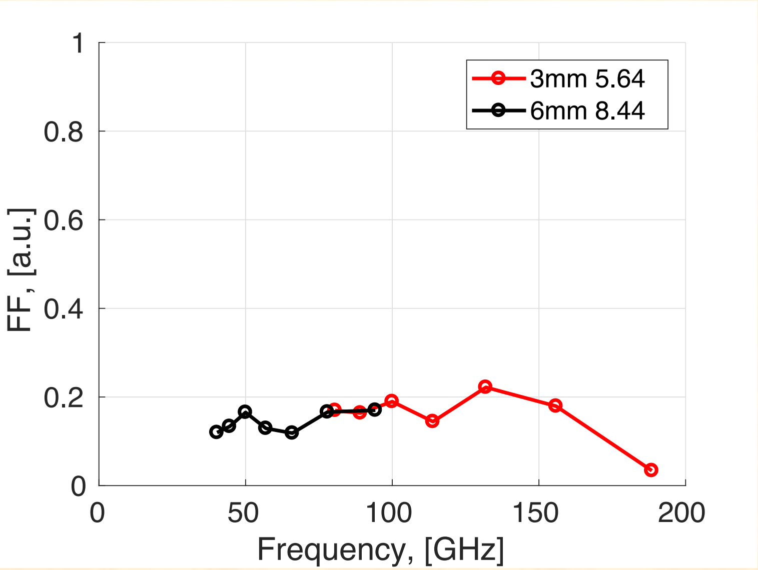


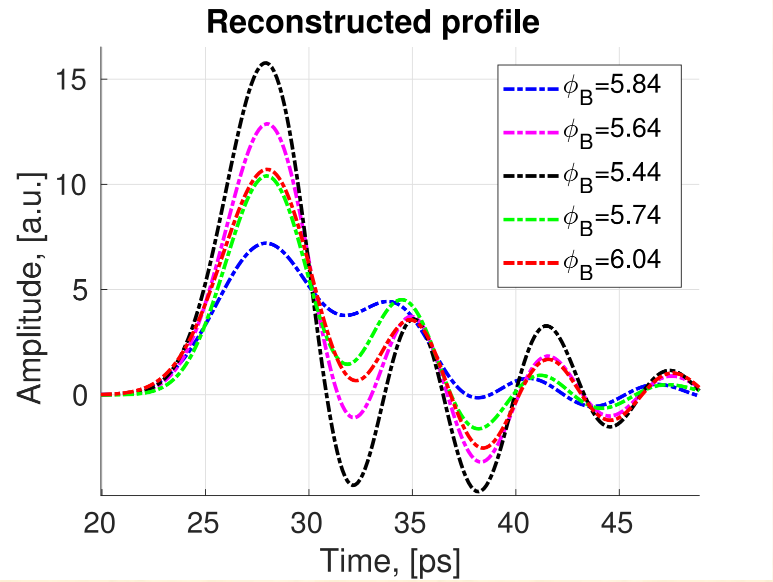




SP @CLIO: Results (4)

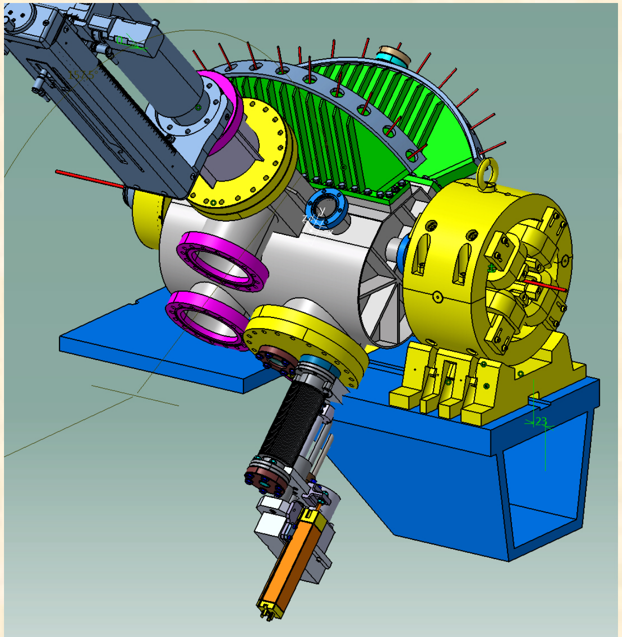
- Results from two different gratings can be stitched together to improve the sensitivity.
- However, this is very artificial as the data were taken on different days.

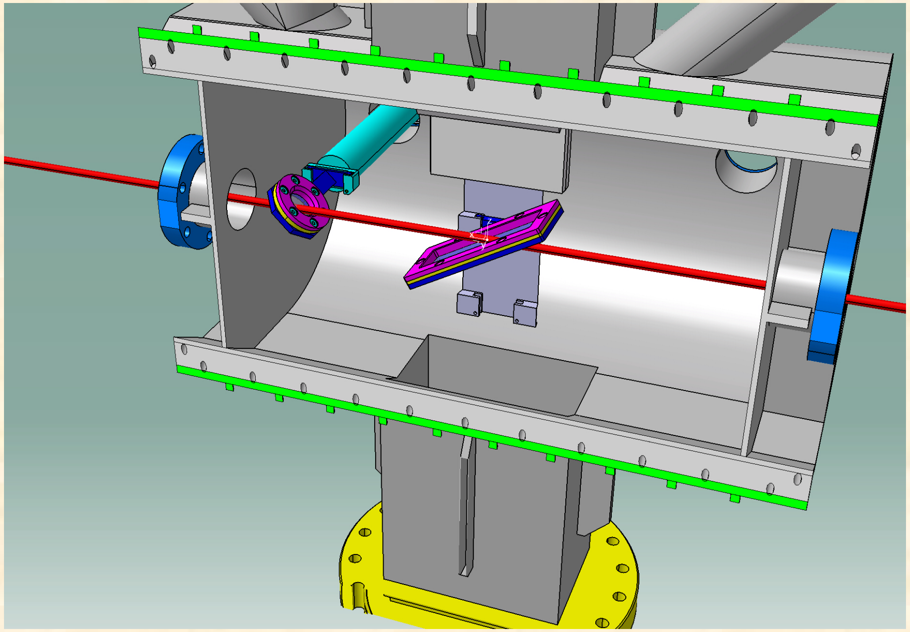




SP @CLIO: Upgrade

- The vacuum chamber needs to be upgraded.
- This will allow measurement with different gratings within a few minutes of each other.





Outlook

- Smith-Purcell radiation can be used as a bunch length diagnostic.
- Several experiments have been done.
- Next steps:
  – single shot monitor on ps beam at CLIO
  – Single shot on sub-ps beam
- Steady progress but very small team!

Thank you!