Microbunching Measurements at FERMI

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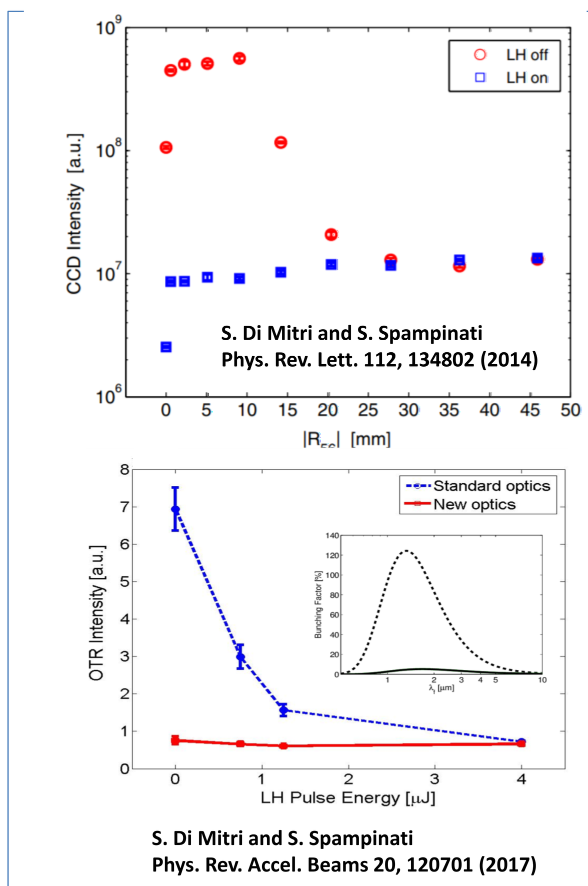
Abstract: Understanding the origin and the evolution of microbunching along the machine is one of the open issues for Free Electron laser (FEL) operational control. Experimental characterization is also not straight forward because of the intricacies of beam dynamics and the wide spectral range of microbunching. At FERMI we have started a campaign of measurements with different techniques along the whole machine. They include intensity characterization of coherent optical radiation (COTR) in the visible range as function of the Laser heater intensity, FFT based modulation analysis at the first bunch compressor (BC1) and at the diagnostics beam dump (DBD) spectrometers. The spectral distribution of coherent transition radiation (CTR)in the IR region was studied with band pass filters and PbSe detectors as well as a new IR scanning spectrometer. We also used the beating of two pulses in the LH to induce narrow band modulation and study of its effects on the FEL spectrum. These techniques and the experimental results obtained so far are discussed in this paper as well as future perspectives.

FERMI is a seeded FEL based on the high gain harmonic generation (HGHG) scheme. Two FEL lines are operational: FEL-1 and FEL-2. FEL-1 is a single stage seeded FEL generating coherent light in the 20-65 nm range. FEL-2 is a double stage seeded FEL based on the fresh bunch injection technique lasing in the range 4-20 nm. A 50 Hz photo-injector GUN delivers bunches with 700 pC. The acceleration to a final energy of 1.5 GeV is provided by an S-band linac. The bunch length is manipulated by two magnetic bunch compressor chicanes (BC1 & BC2).
Microbunching instability (MBI) affects the electron beam quality, and this reflect on FEL performances. For this reason a Laser Heater (LH) is installed at 100MeV beam energy. MBI induced deterioration becomes more relevant as HGHG scheme is pushed towards higher harmonics. Emission at these shorter wavelengths (e.g. FEL1 at 10nm) is usually strongly suppressed by MBI in terms of peak power and spectral purity. New measurements techniques are used at FERMI to study these effects.

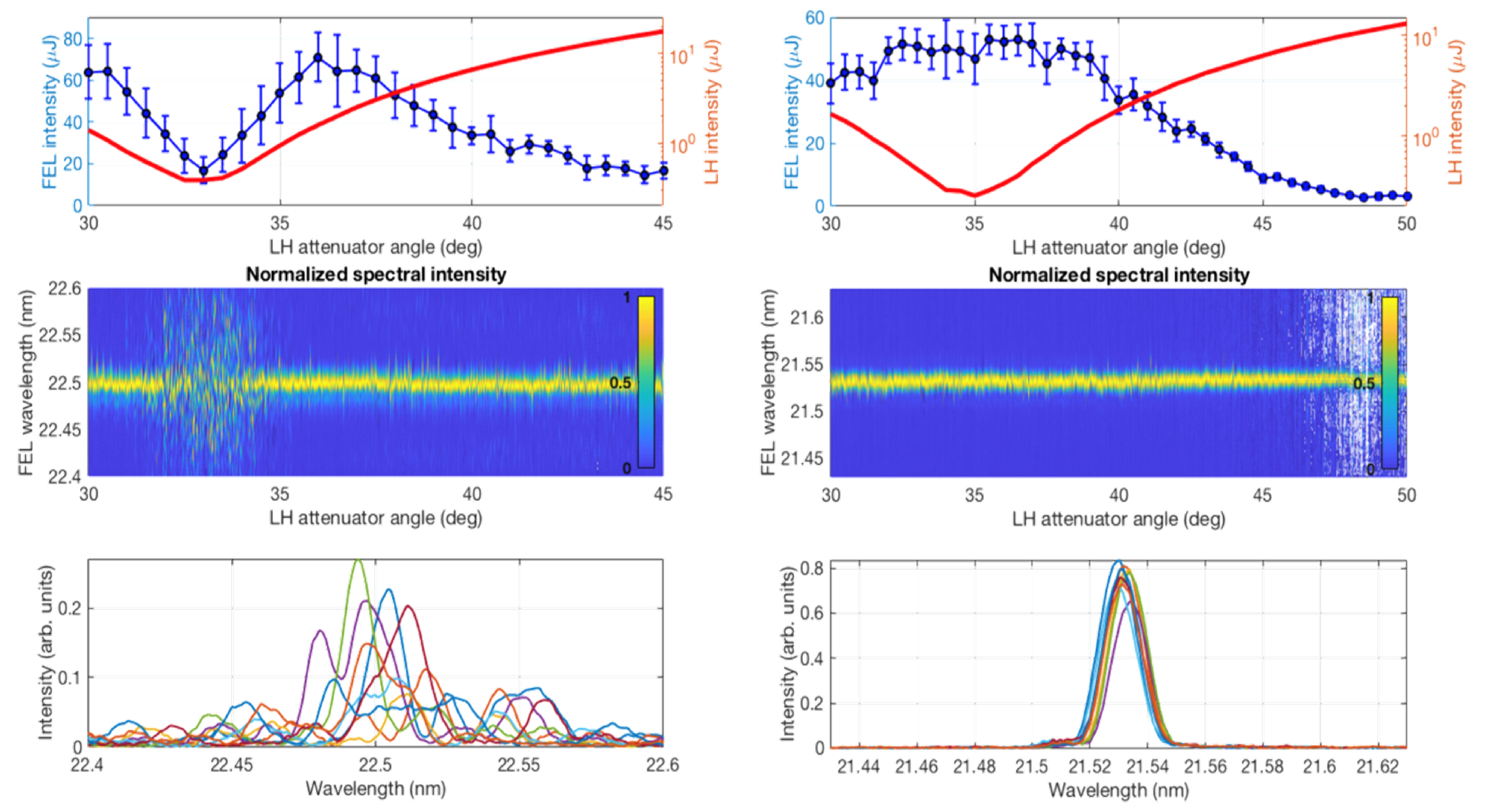


COTR vs LH energy and MBI vs spectral stability:

The coherent optical transition radiation intensity can be used to validate the operation of a LH or to validated the efficacy of new schemes in suppressing microbunching.

In a highly microbunched beam (left figures)
For LH Off (33deg) the FEL power has a minimum. The spectrum central wavelength is very unstable and spectral shape is not a single line. Only as LH energy reaches about 1µJ the energy and spectral purity is restored.

In a beam with low MBI (right figures)
The is no minimum when LH is Off and spectral stability and purity are excellent and stable with LH energy.



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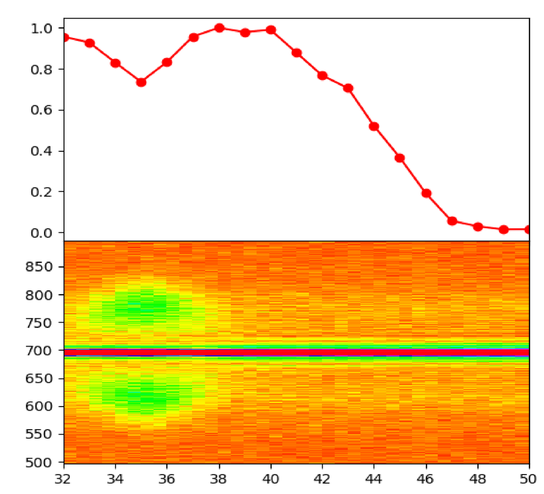


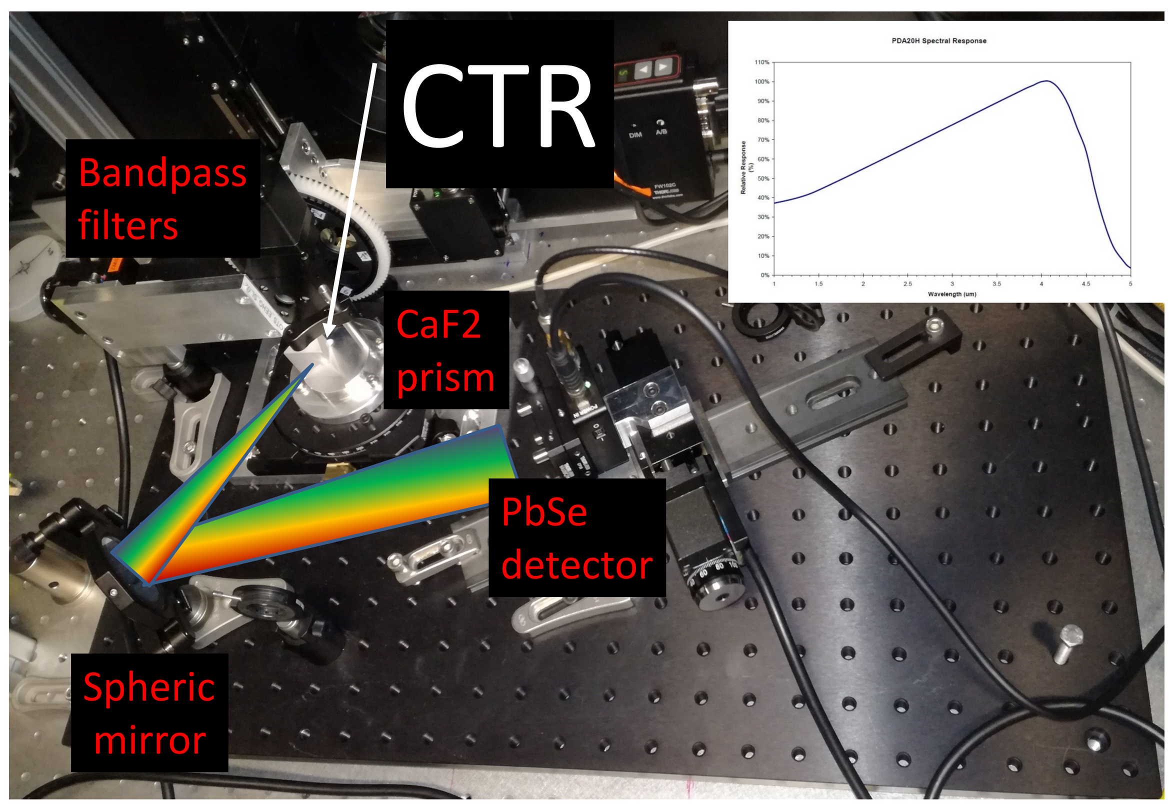
FFT modulation analysis at BC1 spectrometer:
The energy modulation out of BC1 can be converted in a spatial density modulation in the BC1 electron spectrometer. Images at the spectrometer scintillating screen are taken and analyzed via FFT to obtain the spectral distribution of the modulation.

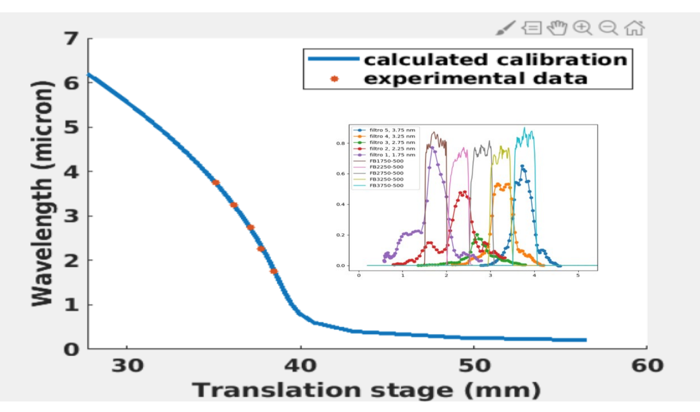
Upper figure : FEL intensity vs LH energy, Lower figure: FFT of modulated e-beam at BC1 spectrometer

Modulation contains a clear structure present for LH Off. This is a fingerprint of microbunching in BC1.

This techniques has been applied to 2D MBI studies in: A.D.Brynes et al. Sci Rep. 2020 Mar 19;10(1):5059. doi: 10.1038/s41598-020-61764-y.

IR COTR spectral distribution with scanning low resolution prism based spectrometer
A simple scanning IR spectrometer has been installed in the in FEL2 to study microbunching at longer wavelengths. The scheme uses a CaF2 prism to disperse the broadband CTR radiation emitted by a metallic foil. A PbSe detector is scanned across the radiation beam and spectra are collected in the 1,5-4,8 micron region. The spectrometer has a resolution of 50-100nm.

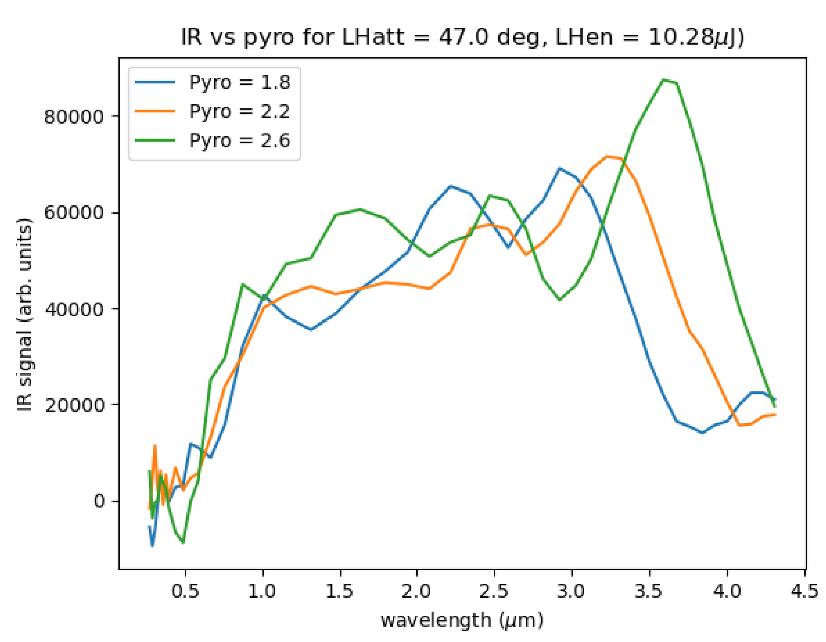


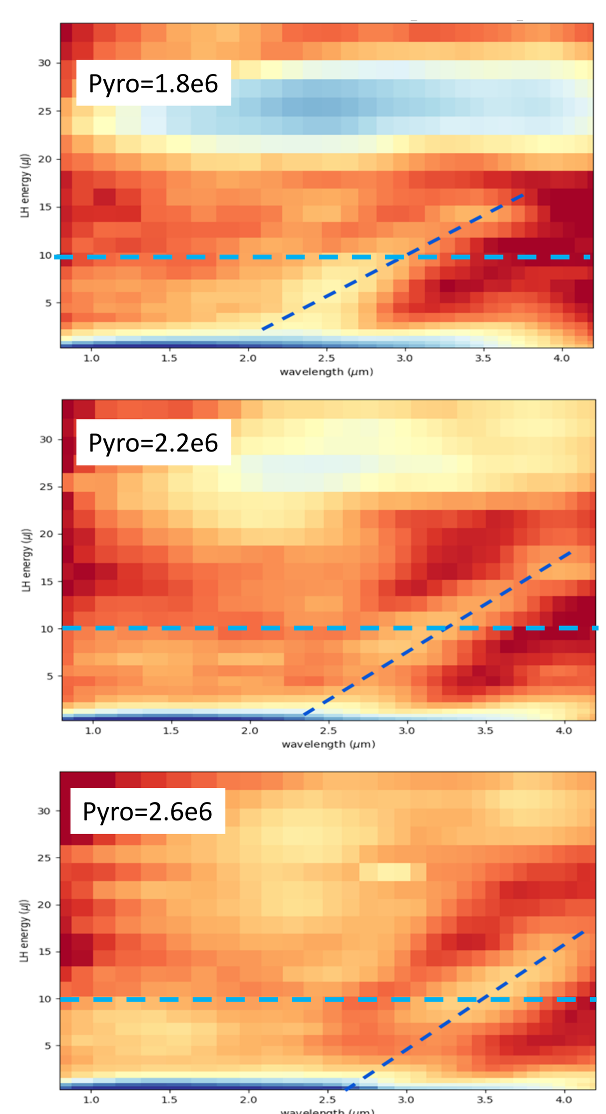


The spectrometer is wavelength calibrated by means of IR band pass filters and analytic description.

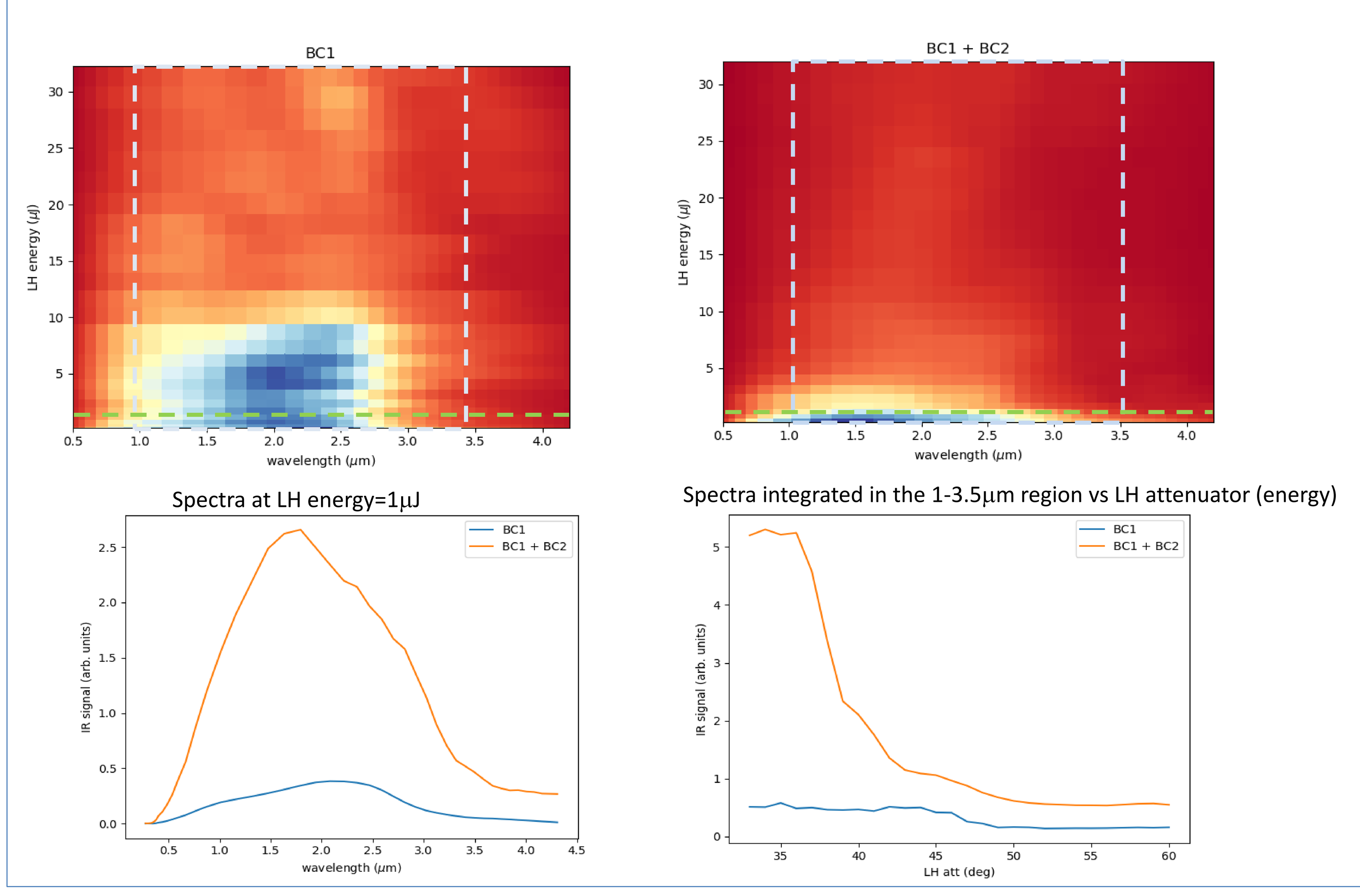
Final data are normalized to the spectral dependence of the detector and of the optical components.

Spectrum vs LH energy at different compressions in BC1





Spectrum vs LH energy for BC1 only and BC1 + BC2



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