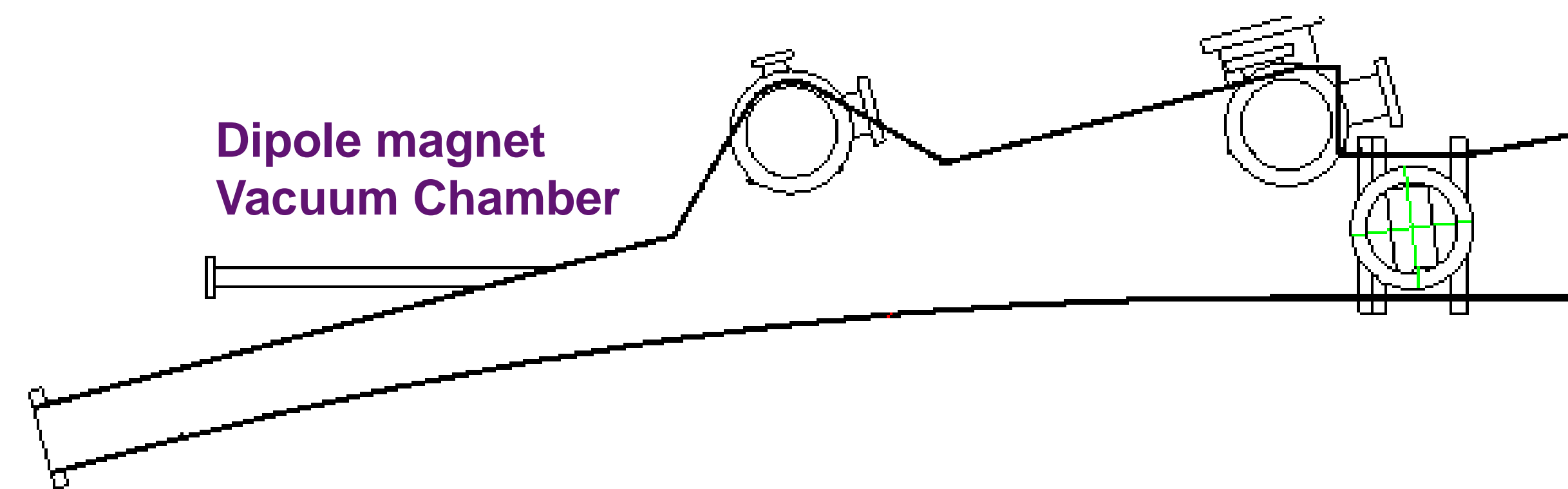


Observation of Multi-bunch Interference with Coherent Synchrotron Radiation

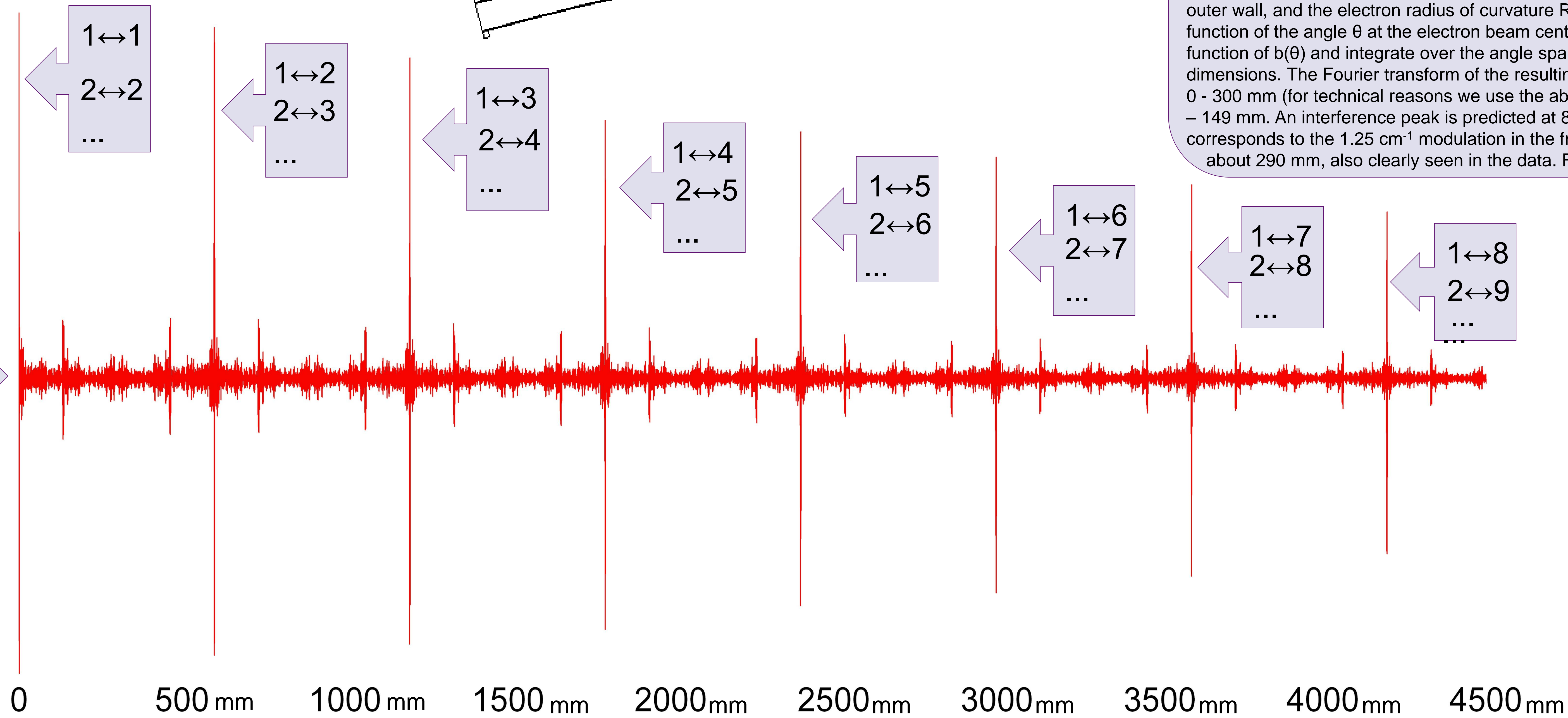
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Introduction: The power spectrum from an electron synchrotron derives from the accumulation of light pulses from successive bunches. For sufficiently short bunches, a unique phase relation exists between successive fields, and a coherency is established between bunches. This bunch-bunch coherency manifests itself in an interferogram as a periodic sequence of patterns similar to the center-burst pattern. We report the first observation of the bunch-bunch coherency from a synchrotron, using coherent synchrotron radiation (CSR) in the far infrared region around 10 cm^{-1} .

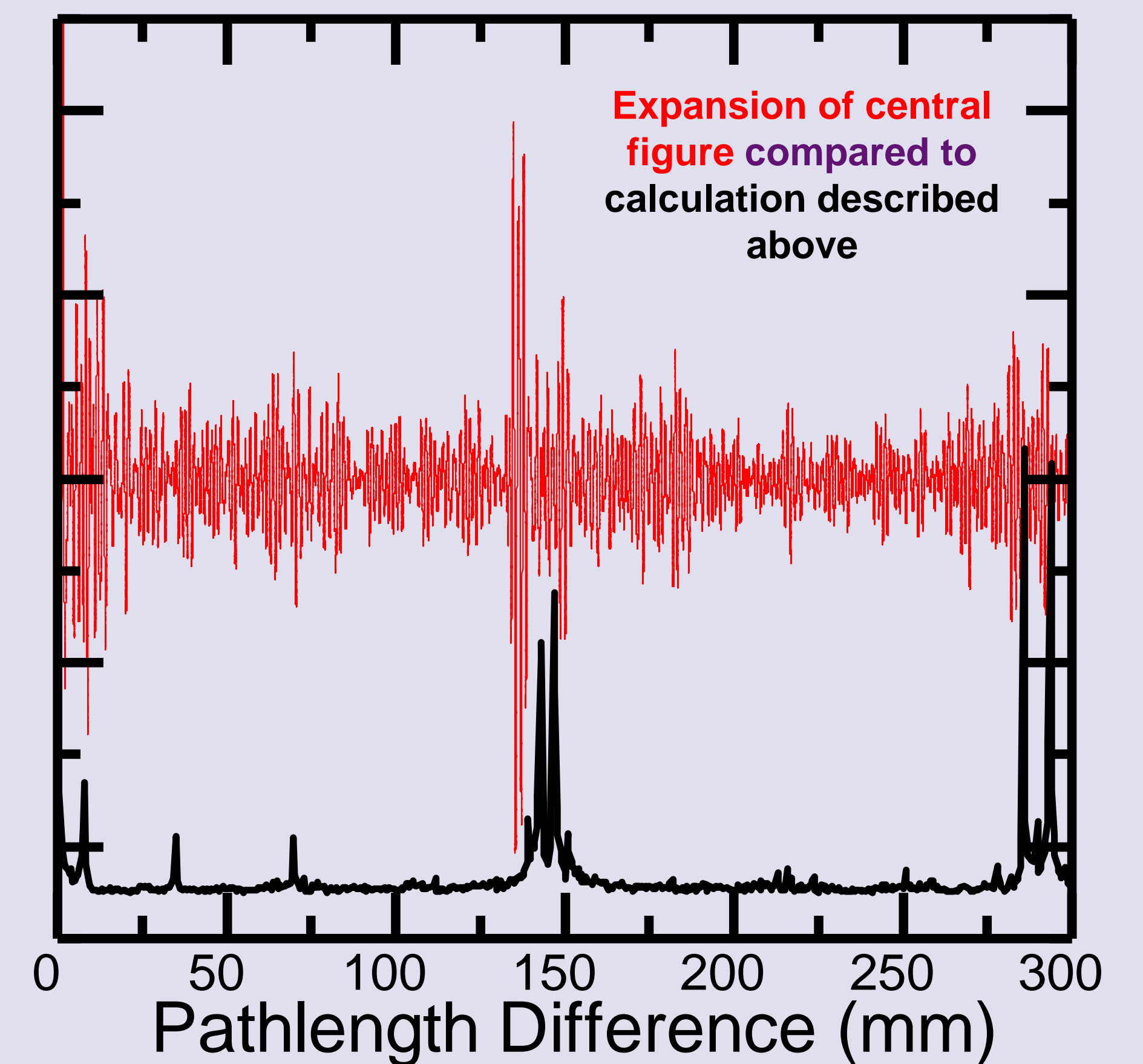


Radiation Impedance: Two other features of the data stand out. First, the interferogram shown in the center exhibits a prominent interference pattern at a pathlength difference of 136 – 149 mm. Second, the frequency spectrum has a modulated appearance, with a period of about 1.25 cm^{-1} , also evident in other CSR spectra at the CLS. We have ruled out internal reflections within the vacuum chamber and vacuum windows as causes. We have therefore explored the possibility that these spectral features are driven by the so-called radiation impedance from the dipole magnet vacuum chamber. The radiation impedance $Z(\omega)/n$ is usually treated as a smooth function of frequency. However, as noted by Warnock and Morton [1], the outer sidewall of a uniform toroidal chamber introduces a series of narrow resonances into $Z(\omega)/n$. The spacing between the resonances is governed by the radius b of the outer wall, and the electron radius of curvature R . For our non-uniform geometry, we let $b(\theta)$ define the outer wall as a function of the angle θ at the electron beam center of curvature. We then treat the longitudinal impedance $Z(\omega)/n$ as a function of $b(\theta)$ and integrate over the angle spanned by the source-path. All parameters are constrained by the chamber dimensions. The Fourier transform of the resulting impedance (un-normalized) is displayed below for path-length differences 0 - 300 mm (for technical reasons we use the absolute value). Significant interference is predicted near the experimental 136 – 149 mm. An interference peak is predicted at 8 mm, consistent with the observed cluster near 8 mm, and which corresponds to the 1.25 cm^{-1} modulation in the frequency spectrum. Further afield, the model predicts a pair of patterns at about 290 mm, also clearly seen in the data. Finally, seemingly absent from our predictions is the pair of interference

CSR was produced by operating the CLS synchrotron at 1.5 GeV, with the momentum compaction adjusted to produce a bunch length of a few picoseconds. Total beam current was ~4.9 mA, distributed over 210 bunches. Spectra were collected on a Bruker IFS 125 HR spectrometer, using a 75 μm beam splitter and Infrared Labs Si Bolometer. A 12.5 mm aperture was used, a 200X gain, a scanner velocity of 60 KHz and a resolution of 0.002 cm^{-1} . Interferogram (up to a pathlength difference of 4.5 m) of the CSR output.



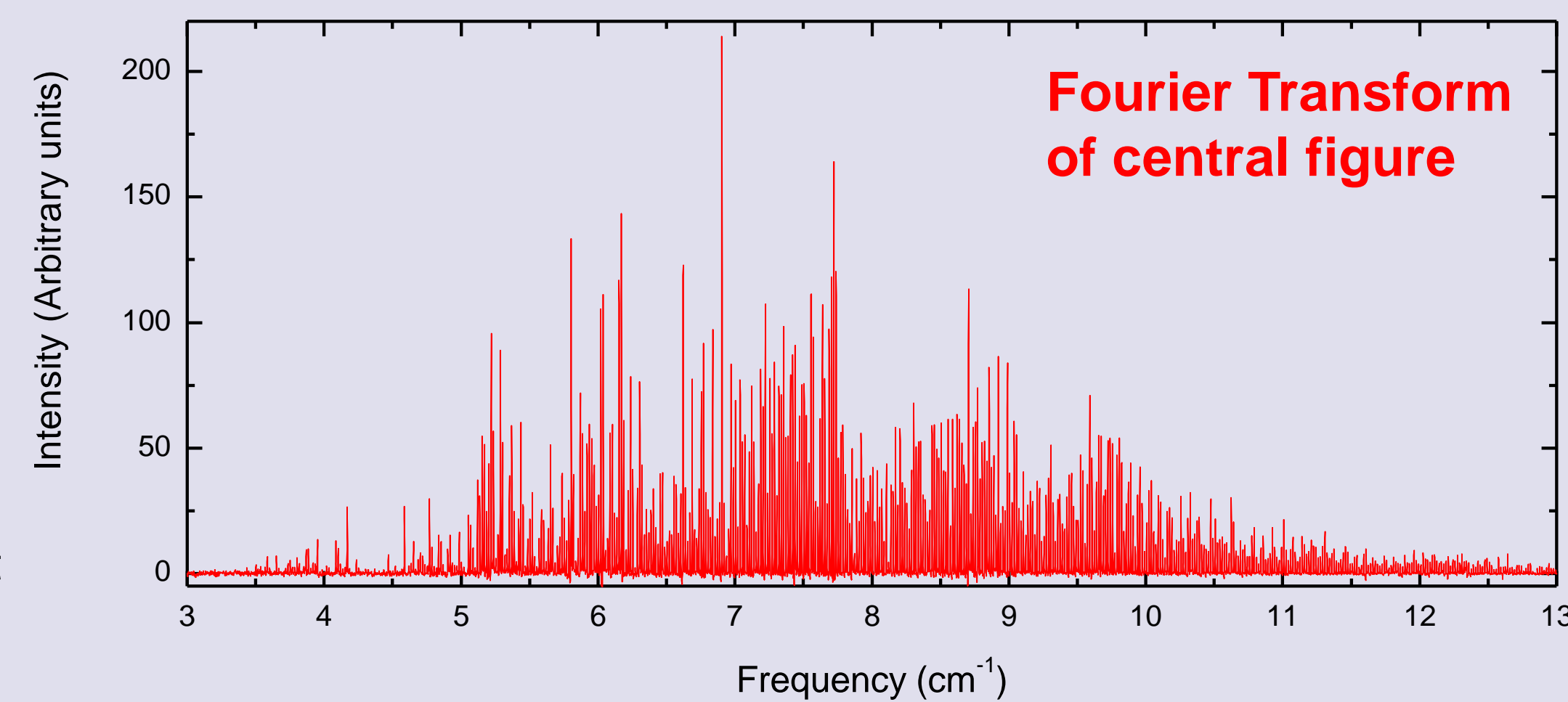
patterns seen around 170 – 180 mm. However, the model does account for them when multi-bunch interference is included. A strong double-peaked pattern is predicted at 430 mm (not shown), with a peak separation of 10 mm, which correlates well with experiment. The downward “reflection” of this pattern from the next burst pattern at 600 mm would manifest itself as a split pattern near 170 mm with a 10 mm spacing, thus correlating with the observed 170-180 mm interference pattern.



1.R. L. Warnock and P. Morton, *Particle Accelerators* 25 113-151 (1990)

Multi-bunch Interference:

The first thing noticed in the interferogram displayed in the center are the center burst like features spaced in 600 mm intervals from 600 mm, to 4800 mm pathlength difference. These features are due to interaction of one bunch with its nearest neighbor, the bunch once removed, twice removed up to 7 respectively.



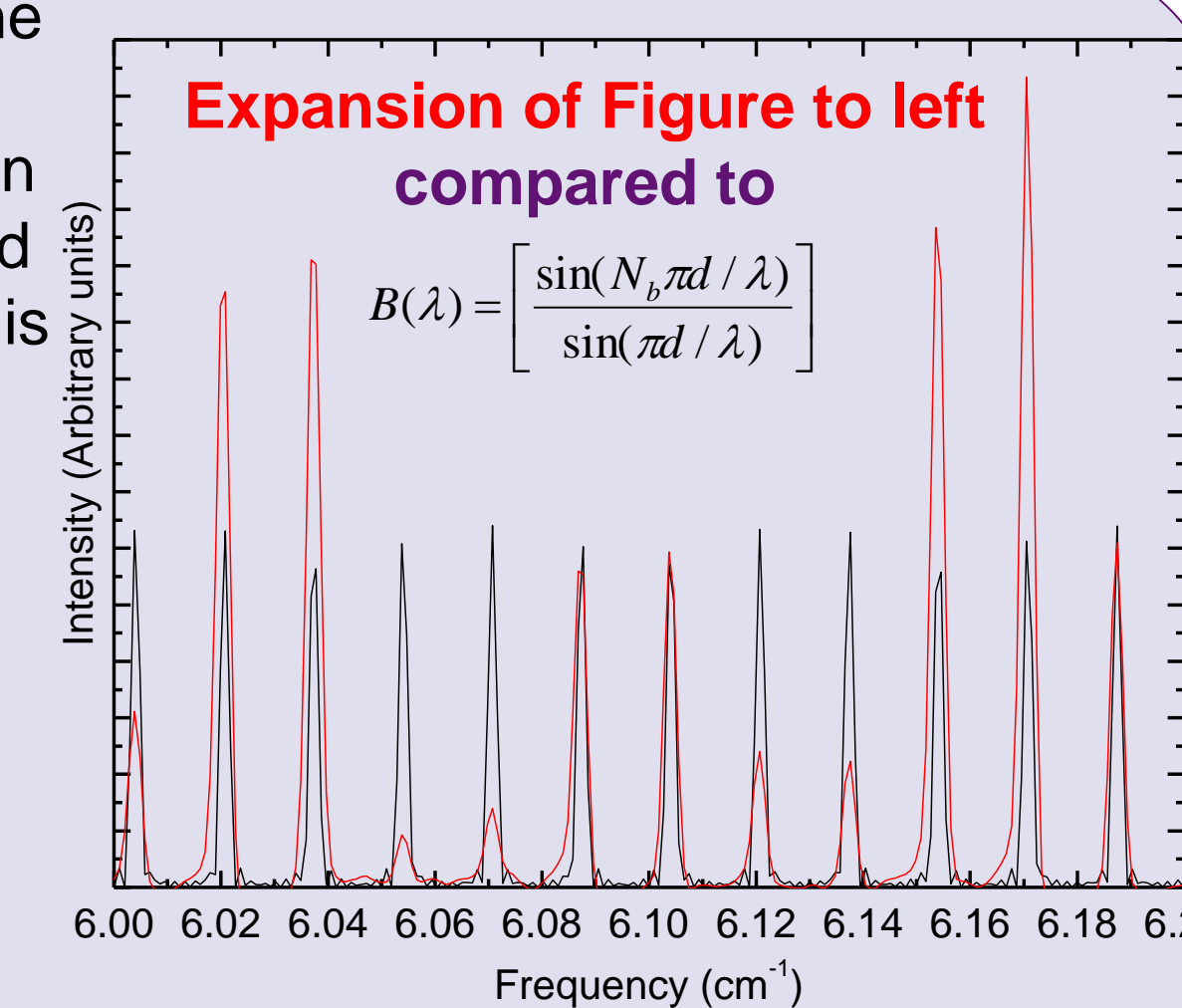
The fourier transform of the interferogram is found to the left shows the sharp spectral features that result from these interactions. These features are more easily observed in the expanded 6.0-6.2 cm^{-1} region shown to the right. The fine structure in these figures can be explained by considering that the intensity of CSR from N_b successive bunches is given by

$$I(\lambda) = N_b^2 \cdot I_e(\lambda) \cdot B(\lambda)$$

where $I(\lambda)$ is the single electron spectrum, $f(\lambda)$ is a bunch length dependent form factor, N_b is the electron population of each bunch and $B(\lambda)$ is

$$B(\lambda) = \left[\frac{\sin(N_b \pi d / \lambda)}{\sin(\pi d / \lambda)} \right]$$

with d the bunch separation (~600 mm). A trace of the second equation is shown in black to the right.



Acknowledgments:

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